A Biodiversity Survey of the New Hope Creek Floodplain and Hollow Rock Nature Park in Durham County, North Carolina

Conducted by the North Carolina Biodiversity Project for the Durham County Open Space Program and Funded by a Grant from Burt's Bees

Authors:

Steve Hall (lead), Nancy Adamson, Blanka Aguero, Jame Amoroso, Brian Bockhahn, Ed Corey, H. Van T. Cotter, Tracy Feldman, Meriel Goodwin, Erich Hofmann, Tom Howard, Kyle Kittelberger, Harry LeGrand, Hannah Levenson, Caroline Martin, Gary Perlmutter, Jim Petranka, John Petranka, Clyde Sorenson, Bruce Sorrie, Bo Sullivan, Carol Tingley, and Elsa Youngsteadt

December 31, 2022

Abstract

The New Hope Floodplain and adjoining natural areas in Durham County were originally identified as priorities for conservation based on biological surveys conducted in the 1980s and 1990s. This report describes a multi-taxa survey of this area conducted in 2021-2022 by the North Carolina Biodiversity Project. The goal was to determine the current status of the biodiversity – the variety of native species and ecological functions -- within this area and what new measures might need to be taken to preserve the integrity of its ecosystem. A total of 1,806 species were recorded during this survey, mainly representing twelve taxonomic groups that were the focus of the study. Rare species, such as the Big Shellbark Hickory, that were provided the basis for the original conservation efforts aimed at this area were determined to be still present and still doing well. Moreover, several new species of conservation concern were recorded for the first time. These include rare slime molds, lichens, fungi, bryophytes, and spiders, all of which were recorded due to the expanded taxonomic coverage of our survey. These findings, along with our confirmation of many of the ecological processes that are still functioning to give this area its special features, all justify a continued high conservation priority for this area. On the other hand, we also found evidence of major impacts to the ecological integrity of this site. The bottomland forest in particular is being ravaged by the attacks of the Emerald Ash Borer, which may eliminate Green Ash as one of the major components of the canopy; a large number of ash symbionts are also being affected with a number of them not found during the survey. Nearly fifty other exotic, invasive species of fungi, vascular plants, insects, mammals, and birds were documented, some having potentially major ecological impacts. Increased flooding – possibly related to climate change – may also be adversely affecting the ground-dwelling species of the floodplain. Our most disturbing discovery, however, was a major loss of diversity and abundance within the Lepidoptera of the study area, a finding that we are still at a loss to explain. A number of birds that previously nested in the area may have been additionally lost as a consequence of the decline of the moth populations. Altogether, the positive as well as the negative findings of this study justify even higher priorities for conservation action than existed previously. The year-long effort and wide diversity of groups we included in the survey have all shown their worth in making this case.

Acknowledgements:

We need to thank Jane Korest and Celeste Burns for proposing this study and for obtaining the grant that made it possible and we thank Burt's Bees for providing that support. Carol Tingley and Parker Backstrom handled the finances for this project; Carol in particular set up a new bank account, established our status as a 501(c)(3) association, and obtained the workman's compensation insurance needed for us to conduct this project. Tom Howard, as always, played a key role as our webmaster, creating the website for the project and developing connections between the NCBP websites and this project's site. The New Hope Audubon Society contributed a number of bird records and we need to thank Bo Howse and Barbara Driscoll in particular for their contributions. Records for fungi were provided by both the Duke Mycology Class, headed by Dr. Rytas Vilgalys, and the NCSU Mycology Class, led by Marc Cubeta. Dr. William "Randy" Miller and team, of Baker University in Kansas, identified the tardigrade species in collected lichen specimens from the New Hope Creek Bottomlands, and Dr. James C. Lendemer of the New York Botanical Garden identified some difficult lichen specimens, including *Micarea soralifera*, here reported as a new state record. Mike Munster, of the NCSU Plant Disease and Insect Clinic, joined us in the field to document the presence the *Ceratobasidium* wilt and along with Matt Bertone identified the presence of the Black Twig Borer from material collected during our survey. Milo Pyne reviewed the plant species list for the project, which includes the records of a plant inventory that he and Rickie White conducted in the study area just prior to our own survey. Several of the leaf-mining insects were determined by Charley Eiseman, who is still rearing some of the specimens collected during the survey. Julie Tuttle found at least two plant species that were not otherwise recorded during the survey. Both of those were first recorded in iNaturalist and we need to acknowledge our use of a number of other plant and animal records that were originally entered into that website or into eBird. Finally, the field trips to the project site were made much more enjoyable by the large number of people who accompanied us during the survey: Becky Elkin, Brendan Moore, Claire Sullivan, Dan J. Meyers, Dee Stuckey, Ed Harrison, Eimy Rivas Plata, Ethan Gates, Jasmine Gibbs, John Gibbs, John Kent, Julie Tuttle, Lori Arent, Marta Nieto-Lugilde, Milo Pyne, Natasha Lücking-Rivas Plata, Savannah Hall, and Scott A. LaGreca.

Table of Contents

Introduction

Assessing the Status of the New Hope Creek Ecosystem in Durham County

Knowledge of the species that inhabit a natural area, along with the ecological functions they perform, is key to effective, science-based conservation. Because of the scarce resources available for conducting biodiversity inventories – including, critically, the number of trained field biologists capable of doing the work – only a few such surveys can be conducted within any year within any given region. Those that are conducted are usually done within a very brief time period and concentrate on just a small fraction of the species that are present-- typically, only vascular plants are included and a few groups of diurnally active vertebrate species. The assumption is that these selected groups can act as surrogates for the rest of the ecosystem. The priority for conservation of a particular site, moreover, is usually determined by the presence of just a very few rare or threatened species belonging solely to these selected groups or to the general quality of the ecosystem as judged from the quality of its vegetation.

Increasingly, fewer and fewer ground-based surveys are being done even based on these limited approaches; traditional field work is being replaced by a combination of remote sensing and predictive habitat modelling. While there is a major benefit to such approaches in that they can cover vast amounts of ground and can keep close track of at least macro-changes in the environment, there is also a growing concern that too much information is being overlooked as a consequence (e.g., see Jenkins et al., 2021). This includes information that is critical for making decisions not just about which sites need the most conservation attention, but how they can be best managed to retain their ecological integrity. With the realization that we actually still depend on the ecological services that healthy ecosystems provide – e.g., production of oxygen, controlled recycling of water and nutrients, buffering against storm damage, cooling the earth, and, of critical importance, sequestration of carbon – this is knowledge that we need now more than ever.

In 2021, Durham County decided to take a different approach. The County's Open Space Program, funded through a grant from Burt's Bees, contracted with the North Carolina Biodiversity Program to conduct a new survey focused on just a single block of natural habitats, the series of county-owned natural areas located along New Hope Creek. This area had been inventoried thirty years ago for both vascular plants (Sutter, 1987; LeGrand, 1999) and diurnal animals (Hall, 1995), resulting in the ranking by the NC Natural Heritage Program of the entire floodplain of this creek and its adjoining slopes as having statewide significance for conservation. Since that time, no comparable surveys have been done within that area despite massive changes that have occurred in its surrounding environment; this is again due to the general lack of resources available for biodiversity surveys.

This new survey, however, is not just a repeat of the old approach. An entire year was given to conduct this survey and instead of focusing on just the few groups of species included in

conventional natural area inventories, the intention here was to include as many different taxonomic groups as possible, each with its own story to tell about the state of its environment.

As will be shown by the results presented in this report, the status of the New Hope ecosystem painted by this survey could not have been obtained using the previous approaches that focus on just a small number of taxa. Going forward, the emphasis in biodiversity conservation will be on management of biodiversity, not just the identification of priority areas for conservation. The information provided by the current survey, in all of its complexity, helps in this regard.

Importance of the New Hope Creek Conservation Corridor

The bottomlands along New Hope Creek in Durham County have long been recognized as having a high value for biodiversity conservation. One of the species found in the earlier surveys, the Big Shellbark Hickory, has one of only a couple of populations in North Carolina located at this site, and another recently discovered species, the White-nymph, has its only known state population in these bottomlands (see White and Pyne, 2021). More generally, the floodplain forest along this section of New Hope Creek is among the most mature and extensive that still exist anywhere within the Piedmont of North Carolina. Trees with diameters (DBH) of at least two feet are common throughout the bottomland and trees with diameters of over three feet are found scattered throughout this area. These include the state champion Big Shellbark Hickory, which has a diameter of 37" and a height of 123' (https://www.ncforestservice.gov/urban/big_species_results.asp, accessed 2022-09-30).

Based on these features, the North Carolina Natural Heritage Program considers the entire series of natural areas along the length of this floodplain as a natural area of state-level significance. The section between the Durham-Chapel Hill Boulevard and NC 54, in particular, is rated as having Exceptional Value, the highest given in the state (NC NHP website, accessed 2022-09-19).

The corridor of natural habitats along the Durham section of New Hope Creek additionally plays a critical role in linking the conservation lands surrounding Jordan Lake, owned by the Army Corps of Engineers, with those located upstream, including the large tracts located within Duke Forest and the Triangle Land Conservancy's Johnson Mill Preserve. As a linked system, these preserves are far more viable than they would be if each section were isolated from one another: local extirpations of species in any one of these areas can be countered by immigration from other sites within the network. This function, moreover, is only increasing in importance as more and more of the surrounding landscape becomes fragmented by human activities.

At an even greater geographic scale, the New Hope Creek natural areas serve as a component within an even larger conservation network. In a recent effort to map sites in the eastern United States that are likely to play important roles as connectors and/or refuges for species moving in response to habitat change (Anderson et al., 2014), the Nature Conservancy has identified an essentially continuous corridor stretching south from the New Hope bottomlands

in Durham County to at least eastern Fayetteville in the Coastal Plain. Although northward movements are more limited due to the barrier created by I-85, there is nonetheless at least some possibility that connections can be restored between the New Hope corridor and the Eno River by creating wider bridge crossings where the headwater streams of both basins cross under the Interstate. If restored, those passages would provide one of the rare opportunities for species – especially those that cannot fly -- to move overland between two river basins.

Efforts to restore and protect these connections, along with the conservation of the natural areas in both the New Hope Creek and Eno River watersheds, are the particular focus of the Eno-New Hope Landscape Conservation Group, who recently published an evaluation of conservation priorities in these two areas (see Tuttle, et al., 2019, https://ncbg.unc.edu/wp-content/uploads/sites/963/2019/12/EnoNewHopePlan_December_2019.pdf). If successful, the restoration of this system of natural areas would extend across at least Durham, Orange, Chatham, and Wake Counties, with still other connections possible throughout the much larger area encompassed by the Neuse and Cape Fear River Basins. In this context, the corridor of high-quality natural areas that exist along New Hope Creek takes on a state- or even national-level significance for conservation planning extending well into the coming century.

Conservation Investment in the New Hope Bottomlands

Due to the recognition of the importance of the New Hope Creek watershed for biodiversity, it has long been the focus of conservation efforts. These began in the 1920s with the acquisition of abandoned farmlands by Duke University, forming the core of the Duke Forest when it was formally created in 1931. These tracts have been managed since that time primarily as working forest lands, supporting forestry teaching and research, but with some areas set aside for outdoor recreation or specifically as Registered Natural Areas (see https://dukeforest.duke.edu/). Two of the Divisions of the Forest, the Korstian and Blackwood Divisions -- like the New Hope Bottomlands – are considered to have Exceptional Quality for biodiversity conservation by the Natural Heritage Program.

Following completion of the natural area inventories conducted in Orange and Durham Counties (Sutter, 1987; Sather and Hall, 1988), an open space master plan was developed specifically for the New Hope Watershed by an inter-governmental body, the New Hope Advisory Committee. Durham and Orange Counties were involved in this effort, along with the cities of Durham and Chapel Hill (Coulter Associates et al., 1991). Among the recommendations of this plan was the protection "through purchase, acquisition of development rights, or donation" of the following tracts:

- The stream courses of New Hope, Dry, Mud, and Sandy Creeks
- Their adjacent floodplains
- The steep slopes (defined as 20 percent or greater) adjacent to floodplains
- Larger tracts of particular historic, educational, or recreational value

Guided by this plan, the Durham Open Space Program acquired a string of parcels along the main stem of New Hope Creek, as well as along Dry Creek on the Orange-Durham County line and an isolated tract on Mud Creek located upstream from its confluence with New Hope Creek. Another key tract, the Hollow Rock Nature Park, was acquired separately as a joint project of the four governments, with additional involvement by the Triangle Land Conservancy (see Hollow Rock Master Plan, 2009).

At the state and national level, the lower portion of the New Hope floodplain in Durham County is protected as part of the Jordan Lake Project Lands owned by the US Army Corps of Engineers. This area, including a substantial part of the study area for the current survey, is administered as a state Game Land by the North Carolina Wildlife Resources Commission. In 2014, this area, along with eighteen other sections of the Jordan Lake Project Lands were registered as Natural Heritage Areas through a Memorandum of Understanding between the Corps and the North Carolina Department of Environment and Natural Resources (see USACOE and NCDENR, 2014). In this MOA, the Corps recognizes the value these areas have in supporting native species and ecosystems and agrees to manage them in consultation with the State's Natural Heritage Program to maintain those values.

One other noteworthy state action that has helped preserve the integrity of this entire system of natural areas was the decision by the North Carolina Department of Transportation to replace the bridge over New Hope Creek at US 15-501 with a span that is much longer and higher than was necessary for vehicular transportation alone. The design of this bridge, instead, was specifically aimed at maintaining the flow of native species through that narrow bottleneck (see Kleist et al., 2007). This project – which had input from the NC Wildlife Resources Commission, NC Natural Heritage Program, the New Hope Advisory Committee, and other local government offices and conservation groups – was the first such wildlife-oriented project by NC DOT in an urban area and done specifically to enhance the movements of all native species, not just deer and other game species (other highway passages elsewhere in the state have been constructed more specifically for Black Bear and other game animals). As such, it serves as a model that can be applied elsewhere, including other sites within the New Hope-Eno Landscape Project Area, where restoration of historic movement corridors is a primary objective (see Tuttle et al., 2019).

Need for a New Biodiversity Survey

The information on the species and ecosystems that supports the conservation priorities of these sites largely comes from biodiversity surveys last conducted in the 1980s and 90s (Sutter, 1987; Hall, 1995; Hall et al., 1999; LeGrand, 1999). While there is always the hope that protecting natural habitats from development or other conversions to human uses would allow native species and ecosystems to continue to exist just as they would in a completely natural environment, such is rarely the case. Particularly where the surrounding landscape undergoes drastic alteration, the impacts of those changes regularly spill across property lines. Small

and/or narrow preserves such as the New Hope bottomlands are especially likely to share some of the same impacts as occur in the adjoining unprotected areas.

Over the past thirty years, the region surrounding the New Hope floodplain has been transformed from a largely rural landscape to one that is rapidly becoming urbanized. Oak Creek Village Shopping Center and other developments along Garrett Road were constructed along the eastern edge of the floodplain in the early 1980s. Following construction of I-40 later in that decade, the area on the western side of the floodplain became even more heavily developed, starting with the creation of the New Hope Commons shopping center in 1985. Within the past ten years, the commercial strip along the Boulevard has continued to expand and apartments and other developments now border the floodplain on both sides, extending along most of the Durham County section of New Hope Creek.

With all of these changes to the entire landscape, a new biological inventory is needed. The continued presence needs to be verified of the rare species and natural community qualities that gave the site its initial priority for protection. Searches can also be made for species that were either overlooked in the original surveys or that have been determined to be of conservation concern after those surveys were conducted. Finally, any adverse changes to the ecosystem must be evaluated so that potential mitigative measures can be considered. Rather than focusing primarily on rare species, the focus of these inventories should be on species that play key roles in maintaining the stability of the ecosystem as well as those that have destabilizing impacts.

Description of the Current Multi-taxa Biodiversity Survey

While there is an ongoing need to resurvey previously identified natural areas in all counties, placing a focus on just a few, very high quality and strategically critical sites allows for the much more in-depth approach that is now essential for conservation management in a rapidly changing world. That is the objective of the current survey: it was explicitly intended to be a true biodiversity inventory, covering as diverse a set of taxa and ecological interactions as possible. In addition to Vascular Plants and Vertebrate Animals – the usual targets of natural area inventories – this survey includes twelve more taxa, some of which, like Fungi, Spiders, Millipedes, and Slime Molds, have never been included in conservation-oriented inventories conducted in North Carolina. Inclusion of these groups does the following:

- Expand the pool of rare and declining species that are the usual basis for setting priorities for biodiversity conservation. In many of these less studied groups, their inclusion in this survey is spurring interest in assigning state ranks to their species. This will allow their inclusion in both the site-ranking protocols used by the Natural Heritage Program and in the novel method of ranking of habitat units and sites used in this study.
- Reveal additional habitat and environmental factors that determine security/imperilment of individual species. Each taxon has its own unique set of life-histories, environmental requirements, and particular threats to their survival. Inclusion

of as wide a range of taxa as possible helps provide as comprehensive an understanding as possible of ecosystem stability/instability.

- Represent as many of the key ecosystem processes as possible. Inclusion of Vascular Plants gives a good representation of primary productivity and inclusion of Vertebrates does the same for secondary consumption (predation on other consumers). However, Insects are the single most important herbivores and additionally play important roles as predators and detritivores. Fungi also play important roles as primary and secondary consumers and are especially important as detritivores. In order to assess how well these vital ecosystem processes are still working, direct surveys of these taxa are a critical need.
- Utilize long co-evolved, highly specific interspecies associations in the description of habitats. We give such associations – biotic habitat factors – as much weight as abiotic factors or structural features in defining habitats. Strong inter-taxa relationships, including herbivore-plant associations or the mutualistic interactions involved in pollination or mycorrhizal symbioses, are used not only to define habitats but are regarded as targets for conservation in their own right.

To conduct this broad, multi-taxa inventory, the Open Space Program contracted the North Carolina Biodiversity Project (NCBP), an organization with wide experience documenting the state's biodiversity. The NCBP is a private, non-profit, 501(c)(3) association founded to obtain information on the complete range of the species inhabiting North Carolina, to disseminate that information as widely as possible, and to develop working relationships with as many partners as possible to support the conservation of this vital resource.

The NCBP currently manages databases and websites for fourteen taxonomic groups with three others currently under development. A website for the habitats of North Carolina is also being created that will deal with the diversity of ecological interactions that underlie the state's ecosystems. Composed of biologists and naturalists with a long history of conducting field work in North Carolina, the NCBP is well-prepared to add multi-taxa field surveys to their list of program objectives.

Organization of the Survey

The approach to conducting this survey falls in between the All Taxa Biological Inventory (ATBI) of the Great Smoky Mountains National Park, which began in 1998 and is still ongoing (see https://dlia.org/about/atbi/), and the series of day-long bioblitzes of NC State Parks organized by Ed Corey, Inventory Biologist with the NC Division of Parks and Recreation. One of the goals of the New Hope survey was to come up with an approach that can be applied more frequently and more widely than the ATBI but which also yields more information on a wide a range of taxonomic groups than can be accomplished during a single day's bioblitz. This approach can be described as an Extended Bioblitz, with each taxonomic group given the same amount of time

to conduct their surveys but allowing them to allocate their efforts over the course of an entire year according to the times that their taxon is most appropriately surveyed.

Nineteen field hours were initially allocated to the fifteen NCBP website groups that existed at the start of this inventory. The selection of survey dates and division of labor was then determined by each group. Some of the groups needed less time to complete their surveys (or could not take part) and this excess time was re-allocated to new groups that emerged during the survey. These included a survey focused on Myxomycetes (Slime Molds) and one on leaf-mining flies and beetles. Birds – which are no longer covered by an NCBP website (transferred to the Carolina Bird Club) – were handled in the same way.

Taxonomic groups covered in this survey include:

- Vascular Plants
- Bryophytes
- Vertebrates (only the four Tetrapod classes)
- Insects (primarily including Odonates, Orthoptera, Moths, Butterflies, and selected families of Beetles, Bugs, and Flies)
- Arachnids (mainly Spiders)
- Myriapods
- Fungi
- Lichens
- Myxomycetes (Slime molds)

Survey Schedule and Description of the Study Area

Field work was conducted between August 1, 2021 and August 1, 2022. As described above, the schedule followed by each taxonomic group varied, the details of which are described in the Taxonomic Summaries that follow. As the survey progressed, updates on the results were made available to the public through a website we created specifically for this project: https://auth1.dpr.ncparks.gov/ncbp_neho/index.php).

A general description of the environmental features of the study area, including past and present land uses, is provided in the project's website and is not repeated here. Instead, the details of the ecological factors that are responsible for shaping the ecosystem along New Hope Creek are described in the Habitat Analysis section of this report.

The map shown in Figure 1 shows the tracts of land included in the survey. The focus was on areas owned and/or managed by the Durham Open Space Program but several adjoining areas that are under some form of conservation management were also included. Permission was obtained to collect specimens specifically from the areas managed by the Open Space Program and a separate collecting permit was obtained to allow sampling on the Game Lands managed by the North Carolina Wildlife Resources Commission.

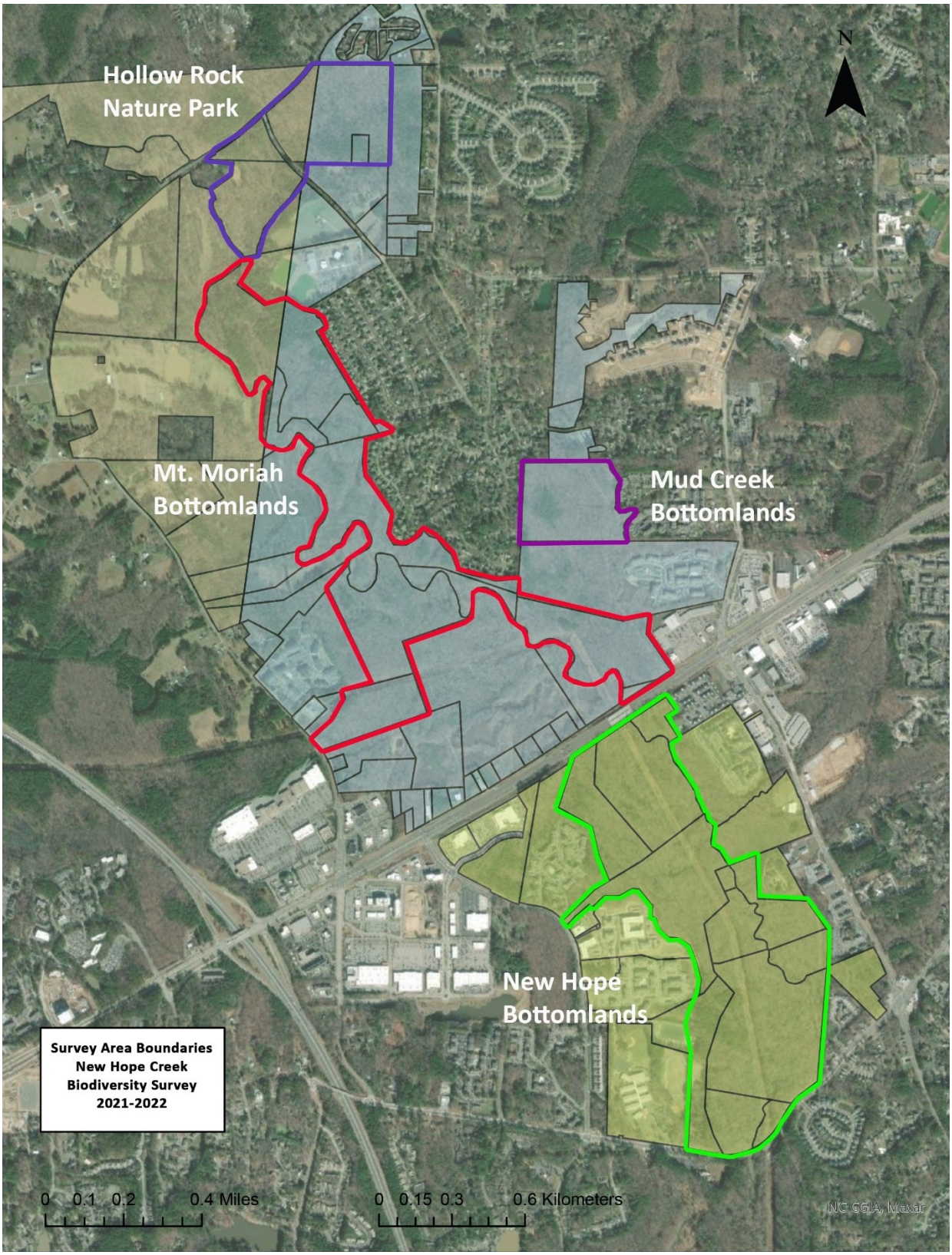

Hollow Rock
Nature Park
Mt. Moriah
Bottomlands
Mud Creek
Bottomlands
New Hope
Bottomlands
N
Survey Area Boundaries
New Hope Creek
Biodiversity Survey
2021-2022
0 0.1 0.2 0.4 Miles
0 0.15 0.3 0.6 Kilometers
NC CGIA, Maxar

Figure 1

References

Anderson, M.G., Barnett, A., Clark, M., Ferree, C., Sheldon, A.O. and Prince, J., 2014. Resilient sites for terrestrial conservation in the southeast region. The Nature Conservancy, Eastern Conservation Science. Available online at: https://easterndivision.s3.amazonaws.com/Terrestrial/Resilient_Sites_for_Terrestrial_Conservation_In_the_Southeast_Region.pdf

Duke Forest Website. Available online at: https://dukeforest.duke.edu/

Great Smoky Mountains All Taxa Biodiversity Inventory Website. Available online at: https://dlia.org/about/atbi/

Hall, S.P. 1995. Inventory of the Wildlife Habitats, Movement Corridors, and Rare Animal Populations of Durham County, North Carolina. Unpubl. Report. NC Natural Heritage Program, Durham County Inventory Review Committee, Triangle Land Conservancy. Available online at: https://digital.ncdcr.gov/digital/collection/p16062coll9/id/331535

Hall, S.P. and Sutter, R.D. 1999. Durham County Inventory of Important Natural Areas, Plants, and Wildlife. Unpubl. Report. NC Natural Heritage Program, Durham County Inventory Review Committee, Triangle Land Conservancy, and Durham County. Available online at: https://digital.ncdcr.gov/digital/collection/p249901coll22/id/183584

Hall, 2005. EEP Tract Evaluation: Penny Tract, New Hope Creek. Unpubl. Report to the NC Ecosystem Enhancement Program. NC Natural Heritage Program.

Hollow Rock Master Plan Committee. 2009. Hollow Rock Master Plan, 2009. Available online at: https://www.newhopecreek.org/preserve/Hollow%20Rock%20Park%20Master%20Plan%20report%20(Final%209-23-09)-2.pdf

Jenkins, D.G., Boughton, E.H., Bohonak, A.J., Noss, R.F., Simovich, M.A. and Bauder, E.T., 2021. Indicator-species and coarse-filter approaches in conservation appear insufficient alone. Global Ecology and Conservation, 28:1-16. Available online at: https://reader.elsevier.com/reader/sd/pii/S2351989421002171?token=CB1CDDF29BC31F24AEBBD53F0CF167979561160C02B63C526B3AD9C7209D4794BA10C2C05DF4AB6DDBC43E058D3484B2&originRegion=us-east-1&originCreation=20221007181815

Kleist, A.M., Lancia, R.A., and Doerr, P.D. 2007. New Hope Creek Bridge as a Wildlife Underpass. Unpubl. Report to NCDOT, North Carolina State University Fisheries and Wildlife Sciences Program, Research Project No. 2004-07 FHWA/NC/2005-11. Available online at: https://connect.ncdot.gov/projects/research/RNAProjDocs/2004-07FinalReport.pdf

LeGrand, H.E. 1999. B. Everett Jordan Project: Inventory for Rare, Threatened, or Endangered Species and Natural Community Inventory. Report of US Army Corps of Engineers, Wilmington NC Office. NC Natural Heritage Program, Raleigh.

North Carolina Biodiversity Project. New Hope Creek Website. Available online at https://auth1.dpr.ncparks.gov/ncbp_neho/index.php

North Carolina Natural Heritage Program Website. Available online at: https://www.ncnhp.org/

Sather and Hall, 1988. Inventory of natural areas and wildlife habitats for Orange County, North Carolina. Unpubl. Report. Orange County Environment and Resource Conservation Department and NC Natural Heritage Program. Available online at: https://digital.ncdcr.gov/digital/collection/p249901coll22/id/184606

North Carolina Forest Service. North Carolina's Champion Tree Database. Available online at: https://www.ncforestservice.gov/urban/big_species_results.asp.

Sutter, R.D. 1987. Inventory of the natural areas and rare species of Durham County. Unpubl. Report. Durham County Inventory of Natural and Cultural Resources

Tuttle, J., B. Massa, O. Munzer, R. Shaw, S. Childs, and J. Randall. 2019. A Landscape Plan for Wildlife Habitat Connectivity, in the Eno River and New Hope Creek Watersheds, North Carolina. Unpubl. Report. Eno-New Hope Landscape Conservation Group. Available online at: https://connectedconservationnc.org/wp-content/uploads/2022/05/EnoNewHopePlan_December_2019.pdf

USACOE and NCDENR, 2014. Amendment to the Memorandum of Understanding between the USACOE and NCDENR for the for the Designation of Significant Natural Areas in The Jordan Lake Project on the North Carolina Registry of Natural Heritage Areas. Available online at: https://files.nc.gov/ncdeq/document-library/Jordan%20Lake%20MOU%20Registry%20Amendment%20January%202015.pdf

White, R. and M. Pyne. 2021. Vegetation Survey of the New Hope Bottomlands. Report submitted to the Durham County Open Space Program. Ecological Experts, LLC.

NCBP Taxonomic Website Groups

The following sections summarize the data collected for each of the taxonomic groups included in the survey. For a detailed description of the individual records, along with selected photographs of the species and habitats, see the website for this project, which continues to be maintained by the NCBP. Lists of these records are available to scientists and conservation groups from the NCBP upon request. The following NCBP website groups participated in this survey:

Slime Molds –website under development; Meriel Goodwin, author

Fungi -- website under development; Van Cotter and Caroline Martin, authors

Lichens – Gary Perlmutter, author

Bryophytes – Blanka Aguerro, Jame Amoroso, and Dave DuMond, authors

Vascular Plants – Harry LeGrand and Bruce Sorrie, authors

Myriapods-- website under development; Carol Tingley, author

Arachnids – Brian Bockhahn, Donald Zepp, Carol Tingley, and Steve Hall, authors

Odonates – Harry LeGrand, Mark Shields, and John Petranka, authors

Orthoptera – Steve Hall and Ed Corey, authors

Hemipteran Hoppers – Kyle Kittelberger, author. Brian Bockhahn, Carol Tingley, and John Petranka conducted the field work for the New Hope survey

Butterflies – Harry LeGrand, author

Moths – Steve Hall, Bo Sullivan, Jim Petranka, Parker Backstrom, Tracy Feldman, and David George, authors

Hymenoptera **(Bees)** – Elsa Youngsteadt, Hannah Levenson, Nancy Adamson, and Steve Hall, authors

Beetles – Steve Hall, Ed Corey, Mark Shields, Jesse Anderson, and Clyde Sorenson, authors

Amphibians – Jim Petranka, Steve Hall, and Ed Corey, authors

Reptiles -- website under development; Erich Hoffman, Steve Hall, Jim Petranka, and Ed Corey, authors

Mammals – Harry LeGrand, Lisa Gatens, Ed Corey, authors

Tom Howard is the web master for all of these projects and also for the website developed specifically for the **New Hope Creek Biodiversity Survey**

Myxomycetes

Myxomycete Biology and Characteristics:

Myxomycetes, also called the Plasmodial Slime Molds, are organisms with a complex life cycle which begins with single celled amoeboflagellates hatched from spores. These at some point join together to produce a multinucleated unicellular mass of free-living protoplasm, often visible to the naked eye (Fig. 1, Fig. 7), which travels over or through the substrate and feeds on bacteria, algae, yeasts, fungal spores, and other organic matter. Under the right conditions this plasmodium transforms into fixed sporocarps, frequently only millimeters in diameter and resembling tiny fungal fruiting bodies (Fig. 8). These reproductive structures mature and release airborne spores which eventually split open to produce a new, mobile amoeba, beginning the cycle again. It is the fruiting body stage which is used for species identification.

With their mix of animal and fungal characters, Myxomycetes have been the subject of mystery and taxonomic speculation since the first recorded observation in the 17th century. Earlier classed with the fungi, they are now normally placed in Kingdom Protista, Phylum Amoebozoa.

As a very ancient organism, Myxomycetes can be found worldwide in all terrestrial habitats from the alpine to deserts. They can fruit on many diverse substrates including living plants such as moss and grasses, but favor dead and decaying wood and leaf litter. When fruiting on living plants they are not pathogenic, but simply use it as a supportive substrate. Particularly abundant in mixed broadleaf temperate forests with alternate periods of wet and dry, Myxomycetes are thus an ideal group of organisms to include in the New Hope Creek Biodiversity Survey.

There are currently more than 1050 morphological species, in 68 genera. 460 species are listed in the Eastern United States, with 196 taxa recorded over two centuries in North Carolina.

Survey Effort:

Because of the seasonality, weather dependency, fragile and transitory nature of myxomycete fruiting bodies, repeat visits were made within short propitious time frames during both Fall 2021 and Spring 2022, for a total of 15 forays during the survey year.

This includes 10 visits between August 31 and November 14th to the New Hope Creek Bottomlands and Hollow Rock Nature Parks, 3 visits in May and early June 2022 to these areas, plus 2 short spring forays in the Mt. Moriah Bottomlands.

Meriel Torrey Goodwin was the principal observer with 45 field hours logged, occasionally in the company of intrepid fellow researchers Gary B. Perlmutter, H. Van T. Cotter, Steve Hall, Carol Tingley, and Caroline Martin. Approximately 50 hours were later spent on species identification, with another 60 hours on processing specimens for entry into the UNC Herbarium, including photographing, mounting, labeling and data base entry into MyCoPortal.

Summary of Myxomycete Species Recorded During the Project:

During the Survey year, 132 myxomycete observations were recorded, with 55 taxa identified (see Appendix 1); 72 vouchered specimens were prepared for the UNC Herbarium. Historical records for the New Hope Creek area are scant, but include 4 taxa not found in 2021-2022*; Lycogala flavofuscum, Perichaena depressa, Trichia varia* and *Tubifera microsperma.*

In the survey area, as is typical in most temperate forests, the vast majority of myxomycete specimens were found on downed tree trunks and branches, with or without intact bark; some specimens were also seen on leaf litter and woody debris.

When the 55 taxa observed during the New Hope Creek Corridor Survey are considered in light of Stephenson's analysis of species frequency in the Eastern US (Stephenson 2020), they represent:

11 species found commonly in the Eastern US,

16 species found occasionally in the Eastern US,

28 species found only rarely in the Eastern US.

The high percentage of rare species (51%) is not surprising given the nature of the New Hope Creek Corridor (NHCC), with its relatively warm, damp climate, high moisture content in the soil, and large numbers of undisturbed downed tree trunks, all positives for myxomycete abundance.

Noteworthy Myxomycete Species:

Amongst the unusual species found in the New Hope Creek Corridor are two taxa new to the North Carolina Myxomycete Checklist: *Stemonitopsis microspora,* and *Cribraria oregana.*

Other rare taxa recorded from NHCC field observations include some of the very smallest species, usually spotted only in laboratory cultures. These include: *Cribraria confusa (*Fig. 2*), Cribaria elegans (*Fig. 3*) Licea kleistobolus (*Fig. 4*)* and *Licea biforis (*Fig. 5*).*

The uncommon species *Oligonema flavidum* (Fig. 6) was seen in quantity on two occasions: Sept. 1, 2021 in Hollow Rock Nature Park on leaf litter and woody debris, and on Nov 1 in the New Hope Creek Bottomlands on a well-rotted oak log. Interestingly, UNC Herbarium accessions show it was also observed in the New Hope Creek area in 1969 by the well-known UNC mycetozoa specialist, Professor Lindsay Olive. Such documented historical persistence of an uncommon myxomycete in a limited geographic area is highly unusual.

In the most exciting find*, Physarum polycephalum* was observed on October 11, 2021 in an extensive (4ft+) plasmodium and fruiting on a large, downed oak trunk in the New Hope Creek Bottomlands (Figs. 7,8). This taxon is easy to culture in the laboratory, and is used in most experiments conducted with Myxomycetes, many in the area of cancer research. According to

Stephenson (1994), it is not particularly common in nature, and indeed as noted from all Herbaria reports in MyCoPortal (www.mycoportal.org), aside from our New Hope Creek Bottomlands observations, there are only 5 other records for all of North Carolina, despite the type being from Wilkes County.

Overall quality of Myxomycete Biodiversity:

The number of myxomycete taxa observed over the New Hope Creek Biodiversity Survey year (T=55), and the 51% ratio of rare species, are clear indicators that the area is an exceptionally propitious habitat for this group of organisms. These numbers are even more revealing of the quality of the NHC corridor, when compared with results from an historical survey of all central Piedmont counties conducted from 1936 to 1940 by UNC doctoral candidate James Doubles, Jr. (1940). His results, over a much longer time period and wider geographic area, include 35 total species, with only 20% of them being in the rare category.

An aspect of the NHCC Survey area which might account for the particular richness of Myxomycetes there, is the diversity of plant species. The rarer myxomycete taxa are thought to have narrow tolerances for pH, light and moisture levels, so a wide variety of microhabitats is a determining factor in their presence in quantity in any one location. In addition, woody debris left undisturbed over a long timeframe is favorable for myxomycete diversity, as different taxa are associated with different decay stages. The lack of human activity in certain parts of the survey area also favors myxomycete abundance, as the organism is sensitive to environmental vibrations especially as it transforms into the reproducing, sporocarp phase.

Conservation Concerns:

The large fruiting of *Physarum polycephalum* found on oak in the New Hope Creek Bottomlands in Fall 2021, was seen again in Fall 2022. This reproducing, highly unusual local manifestation of one of the few economically significant myxomycetes is a great find for its home state of North Carolina, and the location should without fail be conserved for future research purposes.

Myxomycetes are in general an understudied group, so it is unsurprising that their conservation has not received much attention. In 2009 the Species Survival Commission of the IUCN did establish a specialist section which includes the slime molds, and some species are included in a number of Red Data Books and Red Lists of different regions in Europe, but none, to my knowledge, in the United States. One problem overall is the development of good quantitative data for organisms where it is difficult to even define what is an 'individual'.

Schnittler et.al. (2011) suggested that the most appropriate route to conserve Myxomycetes is via a focus on the conservation of the microhabitats where they are found. This approach is particularly applicable to the areas covered in the NHC survey, as the wide variety of unusual myxomycete species recorded there is a sure indicator of the biodiversity value of the locales, and thus argues for a high conservation status for the New Hope Creek Survey area.

References:

Doubles, James Arthur Jr. 1940. *A Taxonomic Study of the Myxomycetes of North Carolina.* Thesis (Ph.D.) - University of North Carolina at Chapel Hill.

Kryvomaz, Tetiana, Tran, Hanh T.M. and Rojas, Carlos. 2021. Uses, applications and disciplinary integration using myxomycetes. In C. Rojas (Ed.) *The Myxomycetes: Biology, Systematics, Biogeography and Ecology, 2nd Ed.* (pp. 493-524); Amsterdam, Elsevier.

Martin, G.W., and C.J. Alexopoulos. 1969. *The Myxomycetes.* Iowa City: University of Iowa Press.

Schnittler, M., Kummer, V., Kuhnt, A., Kriegelsteiner, L., Flatau L., Muller, H., Taglich, U. 2011. Rote Liste und Gesamtartenliste der Schleimpilze (Myxomycetes) Deutschlands. *Vegetationskunde* 70 (6), 125-234.

Stephenson, S.L. and Stempen, Harry. 1994. *Myxomycetes, A Handbook of Slime Molds.* Portland, Oregon: Timber Press.

Stephenson, S.L., Stauffbacher, R.W., and Rojas, C. 2020. Myxomycetes Collected in the Eastern United States and Patterns of Relative Biodiversity. *Mycology* 11(4) 1-10.

Illustrations

Figure 1*: Fuligo septica* - plasmodium

Figure 2: *Cribraria confusa*

Figure 3: *Cribraria elegans*

Figure 4: *Licea kleistobolus*

Figure 5: *Licea biforis*

Figure 6: *Oligonema flavidum*

Figure 7: *Physarum polycephalum* - plasmodium

Figure 8: *Physarum polycephalum* - fruiting bodies

Fungi (Non-Lichenized)

Survey Effort

Seventeen forays to observe and collect fungi were made during this one-year survey, the first on 14 Sep 2021 and the last on 6 Jun 2022. Locations surveyed were Hollow Rock Park and the New Hope Creek Bottomlands with a lesser effort at the Mt. Moriah Bottomlands and Mud Creek Bottomlands.

An estimated 235 field-hours were tallied with more hours than that spent on subsequent identification work. Observers participating in one or more of the forays were H. Van T. Cotter, Marc Cubeta and his North Carolina State Mycology Class, John S. and Jasmine Gibbs, Meriel T. Goodwin, Steve Hall, E. Caroline Martin, Dan J. Meyers, Gary Perlmutter, Carol Tingley, and Rytas Vilgalys with his Duke Mycology Class.

Summary of the Fungal Species Recorded During the Project

From historical records plus new observations made during this one-year survey, 240 non-lichenized fungal species were documented for the New Hope Creek Corridor. Historical records utilized were fungal specimens accessioned in the NCU, DUKE, and BPI Fungal Herbaria plus iNaturalist records that were deemed accurately identified. Of the 240 fungi, only 30 were recorded both in the historic and new observations. Ninety-five species were only documented in the historic records and new observations made during this survey added 115 species.

This survey focused on macrofungi, although some microfungi were also documented. Of note from a biodiversity standpoint is that microfungi are considered to outnumber macrofungi 10:1. This taken together with macrofungal fungal surveys relying on finding fruiting bodies and thus possibly missing most of the macrofungi means that the fungal diversity of the New Hope Creek Corridor no doubt encompasses many thousands of fungal species with circa 1000 of them macrofungi.

Ecologically, over half of the fungal species (129 of 240) are saprobes, decomposers of diverse types. The next largest group is the mycorrhizal fungi accounting for about 30% of the New Hope Creek mycobiota (68 species); oaks and pines are the most common partners of these ectomycorrhizal macrofungi. There were 24 ‘pure’ plant pathogens and 7 mycoparasites documented. Interesting ecological roles include plant endophytes and an insect mutualist. A number of species have multiple ecological roles, say as a saprobe or plant pathogen depending on circumstances.

Noteworthy Fungal Species

Noteworthy fungi found in the New Hope Creek Corridor include three type specimens, one new record for North Carolina, and one fungus likely new to science. Eighteen of the fungi merit consideration for ranking as vulnerable to extirpation from North Carolina; given the paucity of

data on fungal occurrence much work would be needed to determine appropriate state rankings for these organisms. One fungus documented may be an invasive plant pathogen. More detail on these noteworthy fungi follows in subsequent paragraphs.

Fungi for which type specimens were collected along New Hope Creek are *Dacrymyces ellisii, Lactarius subplinthogalu*s, and *Multifurca furcata*. *Multifurca furcat*a (Figure 1) is of particular note as it is very rarely collected – there are only 22 collections in the world fungal herbaria and is a clear candidate for one of the state vulnerable conservation statuses.

Thyronectria aurigera, a tiny ascomycete, is a new record for North Carolina.

A secotioid *Russula* (*Macowanites*) (Figure 2) that was found in the New Hope Creek Bottomlands, appears to be a new species to science based on macroscopic features and molecular analysis (ITS DNA sequence). This is under current investigation.

Boletinellus merulioides (Figure 3) is an intriguing fungus obligately associated with the leafcurl ash aphid, *Prociphilus fraxinifolii*, and ash trees, *Fraxinus*. This fungus feeds off aphid honeydew and in turn provides tiny houses for the aphids on the ash roots.

Of concern is the discovery by Steve Hall of a wilt/dieback disease on *Lindera benzoin* (spice bush) along New Hope Creek caused by a possibly invasive plant pathogen in the genus *Ceratobasidium* (Figure 4); extensive molecular analyses have not yet conclusively determined the species. Invasive plant pathogens have the potential to cause extensive mortality of their plant hosts.

Overall Quality of Fungal Biodiversity

How does the fungal list, compiled for the New Hope Creek Corridor, compare to lists of fungi for other nearby areas? Quite favorably. Taking the five nearest state parks / recreation areas, the number of documented fungi for them ranging from 8 to 99, nowhere near the number documented in this survey. But the caveat is that not much work has been done documenting the fungi in these areas. Taking all of the North Carolina Botanical Garden properties including Mason Farm circa 250 fungal species have been documented for these properties.

Conservation Concerns

Conservation concerns for the fungi mirror those for their hosts and substrates. Thus, the devastating mortality of *Fraxinus* bodes ill for the fungi that are dependent on living ash trees. One noteworthy example is *Boletinellus merulioides*. In the short-term, fungal decomposers specific to ash are experiencing a population explosion, this will crash as the ash substrate is exhausted and without an enduring ash component in the flora these fungi are also imperiled. Many fungi are specific to their hosts (be it as a pathogen, mycorrhizal partner, or decomposer) and their fate is consequently directly tied to that of their host.

The high level of fungal diversity and presence of rare fungi are a testament to the conservation value of the New Hope Creek Corridor with its diverse set of habitats and the importance of preserving them.

Illustrations

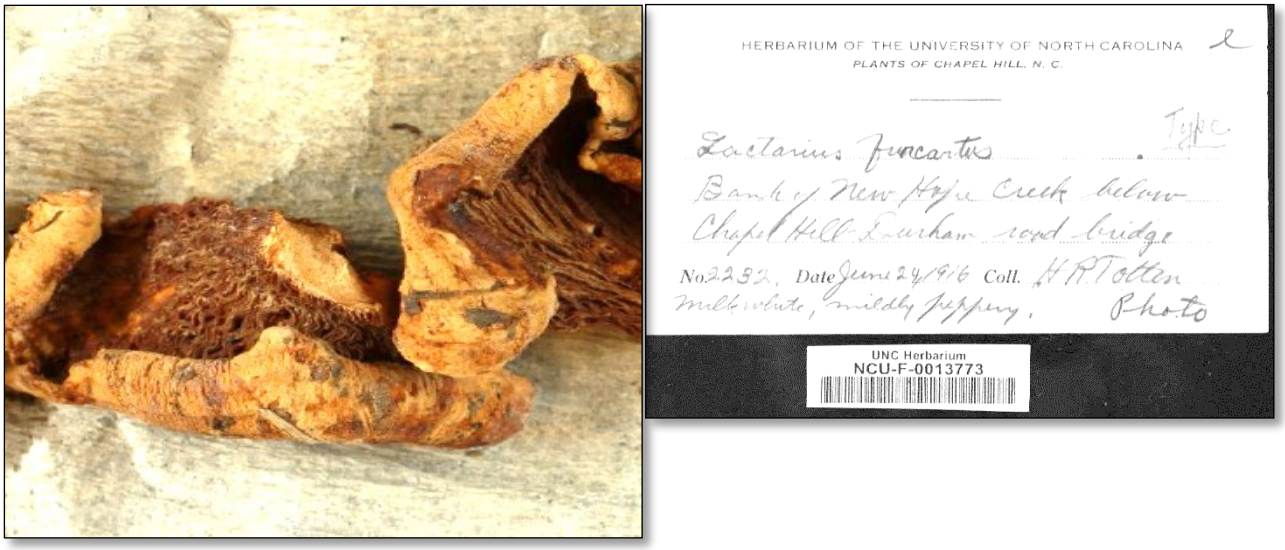


Figure 1. Type specimen of *Multifurca (Lactarius) furcata*.

Figure 2. *Russula (Macowanites) sp*. which appears to be new to science.

Figure 3. *Boletinellus merulioides* collection from the New Hope Creek floodplain.

Figure 4. Wilt and dieback of *Lindera benzoin* believed to be caused by *Ceratobasidium.*

Lichens (Lichenized Fungi)

Biology and Characteristics

Lichens are symbiotic organisms composed of a fungus (mycobiont), an alga or cyanobacterium (photobiont) plus other organisms including bacterial communities and other fungi. Based on this symbiosis with the mycobiont forming the structure (thallus) of the lichen, lichens follow the classification of the mycobiont and thus are considered lichenized fungi. Lichens grow on any stable substrate and come in a variety of growth forms with the three primary ones being crustose (crust-like), foliose (leaf-like) and fruticose (bushy or otherwise three-dimensional).

Often included in lichen surveys are lichenicolous and allied fungi. Lichenicolous fungi are those fungal parasites and commensals that grow on lichen thalli, and thus are collected with lichens. Allied fungi are nonlichenized fungi that are often confused with lichens and collected in lichen surveys; many are in families with lichens and represent species that have lost the lichenized lifestyle within a given family or genus.

Ecologically, lichens function as primary producers, wherein the photobiont produces carbohydrates through photosynthesis, some of which are transferred to the mycobiont to build the lichen thallus structure. Lichens grow throughout the forest habitat, from the floor up to the canopy on any stable environmental surface, including soil, rock, wood of logs and stumps, bark of exposed roots, trunks branches and twigs, pinecones, and evergreen leaves.

The few allied fungi recorded in the New Hope Creek corridor (hereafter NEHO) receive their nutrition from airborne detritus (*Lichenothelia* sp.) or the host substrate, whether that is a tree as saprophobes (*Arthonia quintaria, Arthopyrenia fallaciosa*) or a shelf fungus as a parasite (*Phaeocalicium polyporeum*).

Survey Effort

Ten forays to observe and collect lichens were made during this one-year survey, from November 2021 through July 2022. Locations surveyed included New Hope Creek Bottomlands (26 Nov 2021), Mud Creek Bottomlands (6 and 22 Dec 2021), Hollow Rock Nature Park (12 Feb, 19 Mar, 22 Apr and 1 May 2022), and Mt. Moriah Bottomlands (three sites: Parcel 140148 on 6 May 2022; Parcel 140106 on 9 Jun 2022; and Parcel 138511 on 13 Jul 2022). Collection locations are depicted in Figure 1.

A total of 16.5 field-hours were tallied with 110 hours spent on specimen processing and identification work. Collected specimens were deposited in the University of North Carolina – Chapel Hill Herbarium (NCU) and their records were entered both in the NCBP website for transfer to the NEHO project website, as well as the Consortium of North American Lichen Herbaria (CNALH) website (www.lichenportal.org) wherein a companion lichen checklist was developed. Observers participating in one or more of the forays were Gary B. Perlmutter, Meriel

T. Goodwin, H. Van T. Cotter, Steve Hall, Eimy Rivas Plata, Natasha Lücking-Rivas Plata, and Scott A. LaGreca.

Summary of Survey Results

From historical records plus new observations made during this one-year survey, 104 lichen species plus four allied fungi from 275 vouchered specimens were documented for NEHO. Historical records utilized were lichen specimen records the CNALH website that were deemed accurately identified. Of the 108 species, only seven were recorded both in the historic and new observations. Six species were only documented in the historic records, most of which were from the Duke Forest north of Hollow Rock Nature Park. And new observations made during this survey added 106 species, 29 of which are new Durham County records.

Overall, lichen species were somewhat evenly distributed within the forest profile, with fewest on the floor at 0-0.5 m above ground (24 spp. or 21%), more on the mid-bole level at 0.5-2 m above ground (38 spp. or 34%) and most in the canopy as represented by fallen branches (43 spp. or 38%). All species growing on rock are reported from Hollow Rock Nature Park and Duke Forest.

Noteworthy Lichen Species

The lichen survey in the New Hope Creek Corridor yielded 29 Durham County records and two Orange County records plus one here newly reported for North Carolina. More details on selected noteworthy species are as follows.

Calicium salicinum (Figs. 2A, B) is a new Durham County record and the first modern record of the species in the Triangle. It is a globally distributed lichen found growing on wood and acid bark in moderately shaded areas. This species was collected on decaying wood in Mt. Moriah Bottomlands across the street from Dicks Sporting Goods in an open ash (*Fraxinus*) forest afflicted by the emerald ash borer. The only other record of *C. salicinum* in the Triangle is a specimen in the Farlow Herbarium (FH) from Hillsborough, NC, in nearby Orange County. Examination of the handwriting on the specimen record matches those collected by early American botanist Moses A. Curtis (1808-1872), who resided in Hillsborough and studied mycology in the mid- to latter half of the 19th century (Fig. 3).

Scytinium lichenoides (Fig. 2C) is a new Orange County record as well as the first modern record for the North Carolina Piedmont. Like *C. salicinum*, this species has a wide distribution, occurring in North and South America as well as Europe. This species was collected on shaded mossy rock near the banks of New Hope Creek near Hanging Rock in Hollow Rock Nature Park. The only other records of *S. lichenoides* are two specimens in FH from Salem (Winston-Salem), NC, in Forsyth County. These specimens were first identified by early German-American botanist/mycologist Lewis David von Schweinitz (1780-1834), indicating a gap of about 200 years between the historical and current records.

Bacidia purpurans (Figs. 2D, E) is a new Durham County record and found to be locally abundant in the corridor, recorded in all sites except Mud Creek. It is a recent taxonomic split from the common and widespread *B. schweinitzii* (named after Lewis David von Schweinitz, see above), and reported to be primarily found in humid forests near waterbodies with a scattered distribution in eastern North America (Lendemer et al. 2016). *Bacidia purpurans* is here considered associated with bottomland/riparian forests, along with another crustose lichen, *Arthonia rubella* (Fig. 2F), which is also a county record and locally abundant.

Bacidina delicata (Figs. 2G, H) is newly reported from Durham County and the North Carolina Piedmont with a specimen collected on a fallen branch in Mt. Moriah Bottomlands along with another specimen collected one year prior on a brick in the Woodcroft community of south Durham, just a couple miles SSE of the survey area. Despite its somewhat wide distribution spanning Europe and the Americas, this lichen may be overlooked due to its small size: its characteristic whitish fruiting bodies are only about 0.5 mm in diameter. It also occurs in the Blue Ridge ecoregion.

Micarea soralifera (Fig. 4) is a recently described species from Europe (Guzow-Krzemińska et al. 2016) and later reported from North America via an Indiana checklist (Lendemer 2017); it is here newly reported for North Carolina. This lichen was collected in Mud Creek Bottomlands on the lower trunks of mature pine trees, growing on the edges of bark plates. A search in CNALH yielded specimen records from the North Carolina coast and mountains; the NEHO record here plus earlier observations in Wake County closes the Piedmont gap in the state. The green dust-like thallus probably made this species mistaken for an alga and thus has gone unnoticed despite its widespread distribution in eastern North America and Europe.

Overall Quality of Lichen Biodiversity; Comparison with Previous Surveys

The NEHO lichen biota was compared with those of two previous surveys conducted in similar bottomland/riparian forests: Triangle Land Conservancy's Johnston Mill Nature Preserve (JMNP), located ~4.25 km upstream (Perlmutter 2009), and North Carolina Botanical Garden's Mason Farm Biological Reserve (MFBR), located ~7.35 km SSW in an adjacent creek (Perlmutter 2008), using updated checklists for the two areas in CNALH. NEHO shared 38 species with both JMNP and MFBR with a combined total of 156 species for all three areas. Lichen biotic similarity among the three areas ranged from 36-47% with the greatest similarity being between NEHO and MFBR. These results should be treated with caution as the calculated differences could be due at least in part to sample error (i.e., taxa not reported in a given area could be present but overlooked). In other words, the species richness of a given site should be considered a minimum estimate.

The overall lichen species richness of the New Hope Creek Corridor suggests a largely healthy forest environment. Nitrophilous (i.e., preferring environments high in nitrogen pollution) species *Candelaria concolor, Candelariella xanthostigmoides* as well as pollution-tolerant species (*Physcia millegrana, Pyxine subcinerea, Punctelia rudecta*), reported from urban parks in the Raleigh area (Perlmutter 2010) were found in survey area, nearly all from fallen branches and twigs, representing the more exposed habitats of the canopy. These species were most prevalent

in the Mt. Moriah Bottomlands parcels closest to 15-501 and adjacent shopping centers. Forest interior species found to be pollution-tolerant (*Cladonia ravenelii, Pseudosagedia cestrensis*) from highway-adjacent transects (Perlmutter et al. 2017) were also found on trunks in the study area. *Cladonia ravenelii* was found on pine trunks in New Hope Creek Bottomlands; *P. cestrensis* was found on hardwoods throughout the survey area and in agreement with other surveys, where it was found to be abundant.

By contrast, pollution-sensitive cyanolichens (lichens that have cyanobacteria as the photobiont) were largely absent except for *Leptogium cyanescens*, which is reported to be somewhat disturbance tolerant (Perlmutter 2022). The greatest cyanolichen diversity is reported from the northern part of the study area, where species were found on rocky substrates near New Hope Creek in the Hollow Rock Nature Park and adjacent Duke Forest. This distribution of cyanolichens could also be explained by the distance from the major highway 15-501 and nearby business areas including two major shopping areas of Oak Valley and New Hope Commons. Further, the flood regime of the bottomland forests of the New Hope Creek Corridor could be an additional factor restricting the presence of cyanolichens and lichens on the forest floor in general (e.g., only five species of *Cladonia* are reported).

Conservation Concerns

Conservation concerns for lichens relate to species rarity and population trends. Cross-referencing species found in NEHO against assessment lists of IUCN Red List (https://www.iucnredlist.org/), NatureServe Explorer (https://explorer.natureserve.org/), and the North Carolina Rare Plant List (Wichmann 2021) yielded few matches with most species not assessed or ranked. IUCN has listed Carolina Moon Lichen (*Sticta carolinensis*, Fig. 2I), a cyanolichen found with *Scytinium lichenoides* in Hollow Rock Nature Park, as vulnerable (Lendemer 2020). Another cyanolichen, *Leptogium hirsutum*, collected historically (13 Feb 1969) in Duke Forest, is reported to be of conservation concern based on absence of recent records in much of its range in eastern North America including sites in central North Carolina (Stone et al. 2016, Perlmutter 2022). Less than half of NEHO lichen species were found assessed in NatureServe Explorer with three ranked as apparently secure. No species were found listed in the NC Rare Plant List.

An alternative way of assessing rarity is by county occurrences through specimen records in NCBP and CNALH websites. Species county occurrences can be directly expressed as a percentage of North Carolina's 100 counties. Levels of rarity were set at 10 or fewer counties (up to 10%) for rare and 5 or fewer counties (up to 5%) as significantly rare. Using this method 18 species were found to be rare and 8 significantly rare. The significant rare species include:

- *Anisomeridium biforme*, a crustose species on twigs and branches (canopy)
- *Aspicilia laevata,* a crustose species on rocks (forest floor)
- *Bacidia purpurans*, a crustose species on trunks (midbole), Figs. 2D, E.
- *Calicium salicinum*, a stipitate crustose species on decaying wood (forest floor), Figs. 2A, B.
- *Ionaspis alba*, a crustose species on rocks (forest floor)

- *Phyllopsora isidiosa*, a crustose species on trunks (midbole)
- *Bacidina delicata*, a crustose species on branches (canopy), Figs. 2G, H.
- *Phyllopsora kalbii*, a crustose species on trunks (midbole)

These results also show that lichens as a taxonomic group are largely unrecognized from a conservation standpoint, and work is needed to assess conservation concern of lichen species. Efforts are underway with the NC Natural Heritage Program to update the lichen portion of the state's rare plant list.

The high level of lichen diversity and presence of rare lichens are a testament to the conservation value of the New Hope Creek Corridor with its diverse set of habitats and the importance of preserving them.

References

Guzow-Krzemińska, B., P. Czarnota, A. Łubek & M. Kukwa. (2016) *Micarea soralifera* sp. nov., a new sorediate species in the *M. prasina* group. *The Lichenologist* **48**(3): 161-169.

Lendemer, J. C. (2017) Lichens and allied fungi of the Indiana forest alliance ecoblitz area, Brown and Monroe counties, Indiana incorporated into a revised checklist for the state of Indiana. *Proceedings of the Indiana Academy of Science* **126**(2): 129-152.

Lendemer, J. (2020) *Sticta carolinensis*. The IUCN Red List of Threatened Species 2020: e.T175710250A175710707. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T175710250A175710707.en. Accessed on 10 October 2022.

Lendemer, J.C., R.C. Harris & D. Ladd. (2016) The faces of *Bacidia schweinitzii*: molecular and morphological data reveal three new species including a widespread sorediate morph. *The Bryologist* **119**(2): 143-171.

Perlmutter, G.B. (2008) The lichen biota of Mason Farm Biological Reserve, North Carolina. *Journal of the North Carolina Academy of Science* **124**(3): 82-90.

Perlmutter, G.B. (2009) Lichens of Johnston Mill Nature Preserve, a preliminary checklist. *Native Plant News: Newsletter of the N.C. Native Plant Society* **7**(4): 12-15.

Perlmutter, G.B. (2010) Bioassessing air pollution effects with epiphytic lichens in Raleigh, North Carolina, U.S.A. *The Bryologist* **113**(1): 39-50.

Perlmutter, G.B. (2022) Lichens and allied fungi of Mitchell Mill State Natural Area, North Carolina, USA. *Evansia* **39**(1): 43-53.

Perlmutter, G.B., G.B. Blank, T.R. Wentworth, M.D. Lowman, H.S. Neufeld & E. Rivas Plata. (2017) Effects of traffic pollution on forest lichen community structure in western Wake County, North Carolina, USA. *The Bryologist* **120**(1): 1-10.

Stone, D.F., J.W. Hinds, F.L. Anderson & J.C. Lendemer. (2016) A revision of the *Leptogium saturninum* group in North America. *The Lichenologist* **48**: 387–421.

Wichmann, B. (2021) *Natural Heritage Program List of Rare Plant Species of North Carolina, Revised October 2021*. North Carolina Natural Heritage Program, N.C. Department of Natural and Cultural Resources, Raleigh, NC, 187 pp.

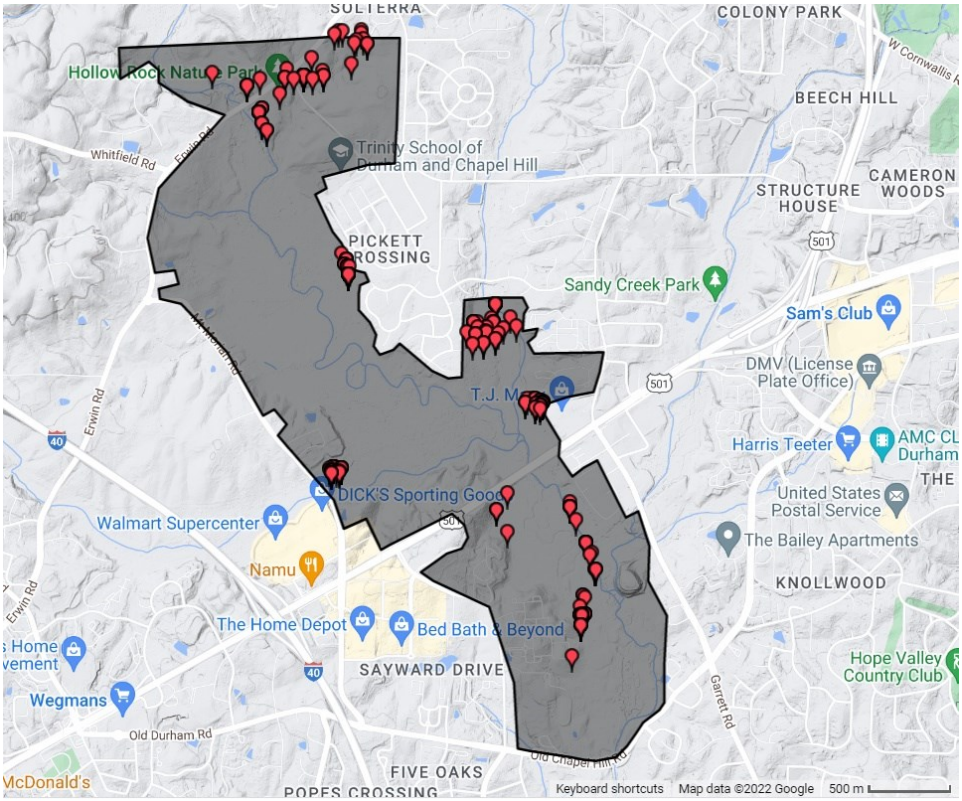


Figure 1. Map of lichen collection sites in the New Hope Creek Corridor (including historical locations).

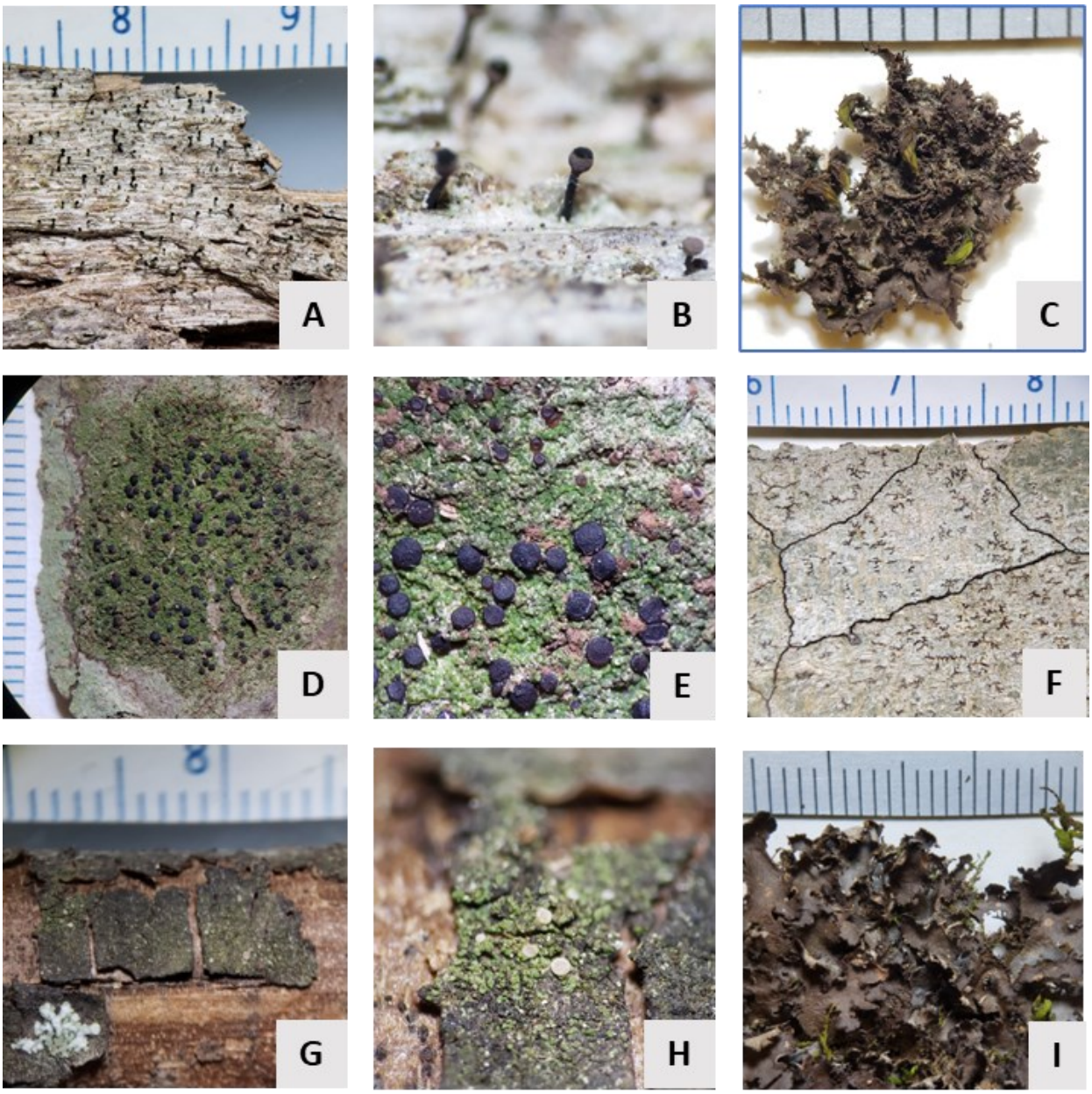


Figure 2. Noteworthy lichens of New Hope Creek corridor. A, B. *Calicium salicinum.* C. *scytinium lichenoides.* D, E. *Bacidia purpurans.* F. *Arthonia rubella.* G, H. *Bacidina delicata.* I. *Sticta carolinensis.* Ruler graduations are 1 mm.

Figure 3. Comparison of handwriting on *Calicium salicinum* (syn. *C. trachelinum*) specimen by an anonymous collector with that another lichen collected by M.A. Curtis, suggesting both were collected by Curtis.

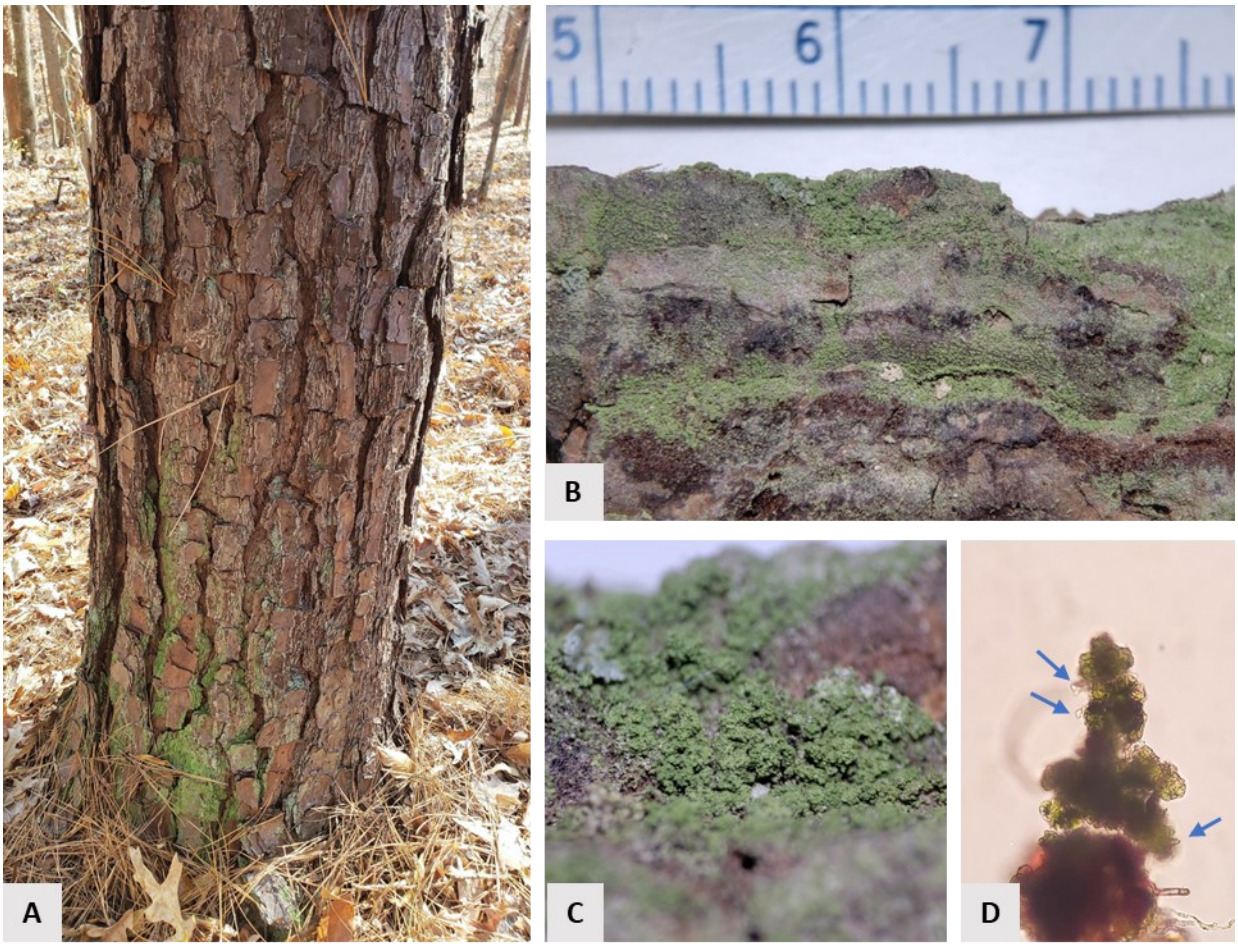


Figure 4. *Micarea soralifera* "Green Dust Lichen". A. field image on Loblolly Pine tree base in Mud Creek Bottomland. B. Specimen. C. Close-up of soralia. D. microimage of soredia/granules showing fungal hyphae of the mycobiont (arrows) and green algal cells of the photobiont.

Bryophytes

Biology and Characteristics

Bryophytes are a group of land plants that reproduce by spores. The bryophyte life cycle is characterized by alternation of generations; its haploid stage is the dominant stage (green photosynthesizing gametophytes, consisting of leafy or thallose stems producing gametes), whereas its diploid stage develops after fertilization, forming a sporophyte, consisting of seta and capsule, that is attached to, and dependent on, the gametophyte. Bryophytes are non-vascular plants, which means they do not form xylem and phloem in vascular bundles. They do not form lignin, and that limits their body size. They lack an active mechanism of keeping water in their bodies, and that limits their growing environment. Bryophytes do not have roots. Each bryophyte cell is capable regenerating into new plant in favorable conditions, and vegetative reproduction by gametophyte fragmentation and/or by forming asexual propagules is frequent.

Bryophytes include members of three plant divisions: Bryophyta (mosses), Marchantiophyta (liverworts), and Anthocerotophyta (hornworts). All three groups were surveyed. They consist of some 20,000 species worldwide, around 2,000 species in North America, and about 700 taxa in North Carolina.

Species names follow the nomenclature used at https://www.bryonames.org/ (Brinda & Atwood 2022, a resource using the Tropicos database, and curating or including taxon acceptance).

Survey Efforts

Bryophytes were surveyed on nine days between Feb 28 - Mar 20, 2022, and on July 26, 2022. Spring time is convenient for bryophyte surveys, as it allows capturing species with an ephemeral life strategy. Locations surveyed included New Hope Creek Bottomlands (2/28, 3/4, 3/20), Mud Creek Bottomlands (3/1 and 3/3), Mt. Moriah Bottomlands (3/8, 3/11, 3/15), and Hollow Rock Nature Park (3/14, 7/26). Collection locations are depicted in Figure 1.

Sampling involved searching for species growing on soil, rocks, bark of living trees, as well as rotting wood in a variety of moisture and light exposure conditions. Species identifiable by using hand-held 20x magnifying lens without microscopic examination were noted in recording cards in the field. Most bryophyte species require dissection of plants, and observation of gametophytic and/or sporophytic character under 10-400x magnification in light microscope. For this purpose, small collections were made in brown paper bags, air dried, and stored for further examination. Fifteen days were spent on plant identifications in Duke University Herbarium, where vouchers for this study are stored.

All sampling was done by Blanka Aguero, Marta Nieto-Lugilde, and Jame Amoroso.

Summary of the Bryophyte Species Recorded During the Project

In total, 102 species of Bryophytes were identified during the survey: one hornwort, 20 liverworts, and 81 mosses.

Both Orange and Durham counties have been well surveyed in the past because of the proximity to Duke University, where bryology has thrived since 1930s. NSF-sponsored efforts to digitize natural history collections during the past decade resulted in the creation of the Consortium of North American Bryophyte Herbaria (CNABH), and CNABH website (www.bryophyteportal.org). Survey results are evaluated using this resource.

CNABH was searched for records from the study area. A total of 56 bryophyte species were recovered for the Hollow Rock area in the bryophyte portal. This area was visited multiple times between 1928-1938 by Duke botanist Hugo Blomquist. Alexander W. Evans collected 2 liverwort species in March 1938, that were not relocated in 2022. Seven specimens were collected by M. R. Robertson in late spring on Apr 20, 1964, including a thallose liverwort *Dumortiera hirsuta*. Anderson located the liverwort a couple weeks later, and it was not observed in 2022. Over 600 records (162 bryophyte taxa) exist in herbaria across US from Durham and Orange County along New Hope Creek. However, the label data indicate either Duke Forest (Korstian Division upstream from the survey site, rich in bryophytes due to the very high diversity of suitable microhabitats), or Hollow Rock. Specimens from the bottomland below the Hollow Rock have not been found.

Diversity of species by sites, as surveyed in 2022, shown as total (mosses/liverworts/hornworts):

Hollow Rock Nature Park: 75 (57/17/1)

Mt. Moriah Bottomlands: 58 (46/12/0)

Mud Creek Bottomlands: 52 (42/10/0)

New Hope Creek Bottomlands: 53 (40/13/0)

Diversity of species by sites, including the historical records, for Hollow Rock: additional 13 liverworts were reported (8 species of liverworts recorded previously were confirmed), and 22 species of mosses (20 species of mosses recorded previously were confirmed). It is apparent that historical collecting in Hollow Rock has not been exhaustive. The majority of bryophyte species found in the herbaria from visits 96-58 years ago are either charismatic, difficult to identify, or rare in the area.

Noteworthy Species

A. Noteworthy species found in 2022

Brachelyma subulatum. This is an aquatic moss, growing on tree bases and cypress knees in cypress swamps. Its distribution is limited to the low elevations of Southeastern US, with one disjunct collection from Hawaii. It has not been collected in NC since 1985.

Fontinalis sp. is a genus of aquatic plants growing on rocks and roots submerged in slow to fast moving rivers and streams. It is difficult to identify due to its morphological plasticity. Together with *Fissidens fontanus*, it grows submerged in clear to weakly polluted running water in rivers, and its presence has been used as indication of water quality and pollution (for example, Cenci 2000).

*Hypnum fauri*ei. This forest species of bark and rotting wood exhibits disjunct distribution between eastern US and eastern Asia. In NC, it is scattered in the Mountains, with only four collections reported from the Piedmont and one collection from the Coastal Plain.

Taxiphyllum alternans. Only one site has been previously recorded from NC (Macon Co., Bryson Branch Falls, 0.8 mi SE of Cullowhee Gap, Cowee Mts.) by L.E. Anderson, Oct 15, 1973. Plants were growing on limestone near waterfalls. One of Anderson's duplicates at MICH for collection number 21218 of *T. alternans* was annotated by R.R. Ireland as *Taxiphyllum deplanatum* (Bruch & Schimp.) Fl. This indicates that this collection is either misidentified, or it is a mixed specimen collection with both species present, and it needs to be further evaluated. Only a handful of records exist from the low elevations of Southeastern US from mucky soils, rotten wood, *Taxodium* knees, in hardwood and *Taxodium* swamps. This species exhibits disjunct distribution between eastern US and eastern Asia, where it also occupies wetland sites, and edges of waterways.

B. Noteworthy species not recollected in 2022

Dumortiera hirsuta. This thallose liverwort does not tolerate desiccation. Two historical records exist from our area, Hollow Rock (on undersides of projecting ledge, edge of creek), and “The Caves” (on undersides of projecting ledge, edge of creek) along New Hope Creek. It is possible that the locality still exists and we missed it. The only rock outcrop visited along the Loop Trail of Hollow Rock hosted a population of *Conocephalum conicum*, and *Dumortiera hirsuta* was not observed. The river edge is disturbed there, the rock is mostly exposed to sun and the north-facing rock wall could currently support *Dumortiera* only if it was either permanently shaded or dripping.

Riccia spp. – *Riccia* species are ephemeral, collected opportunistically, and we have not found any populations during our survey. In North Carolina, they have been repeatedly observed in the Coastal Plain in river floodplains and Carolina bays. The species survive via spore banks, and their abundance is declining with widespread use of chemicals in arable fields.

Comparison to Similar Sites

A dataset for comparison from any similar site in our area is not available. Given the low diversity of suitable microhabitats in the swamp itself, the observed diversity of bryophytes indicates a well-preserved habitat with good availability of rotten wood in diverse stages of decay. The higher diversity observed at Hollow Rock is proportionate to the increased availability of diverse microhabitats (dry, moist, wet rocks) at that site.

Conservation Concerns

Table 1. List of 2022 taxa with a NC state status. Conservation Rank codes follow NatureServe methodology, using S for subnational units, such as state boundaries, and G for Global distribution. The lower the number, the rarer the taxon is with a status of 1 designating critical imperilment, 2 is imperiled, 3 vulnerable, 4 apparently secure, and 5 secure.

NC Natural Heritage Program status definitions for SR-O and SR-D and W7:

- Significantly Rare-Disjunct (SR-D), the species is disjunct to NC from a main range in a different part of the country or world
- Significantly Rare-Other (SR-O) - the range of the species is sporadic or cannot be described by the other Significantly Rare categories
- W7 is an NCNHP conservation status category for taxa that are poorly known in NC, further information is needed to determine the true status in NC. (Wichmann and Wojcik 2022).

Scientific name	State Status	State Conservation Rank	Global Conservation Rank
Brachelyma subulatum	W7	S2?	G4G5
Fissidens fontanus	W7	S2?	G5
Hypnum fauriei	W7	S2?	G5
Taxiphyllum alternans	SR-O	S1	G3?
Warnstorfia fluitans	SR-D	S1	G5

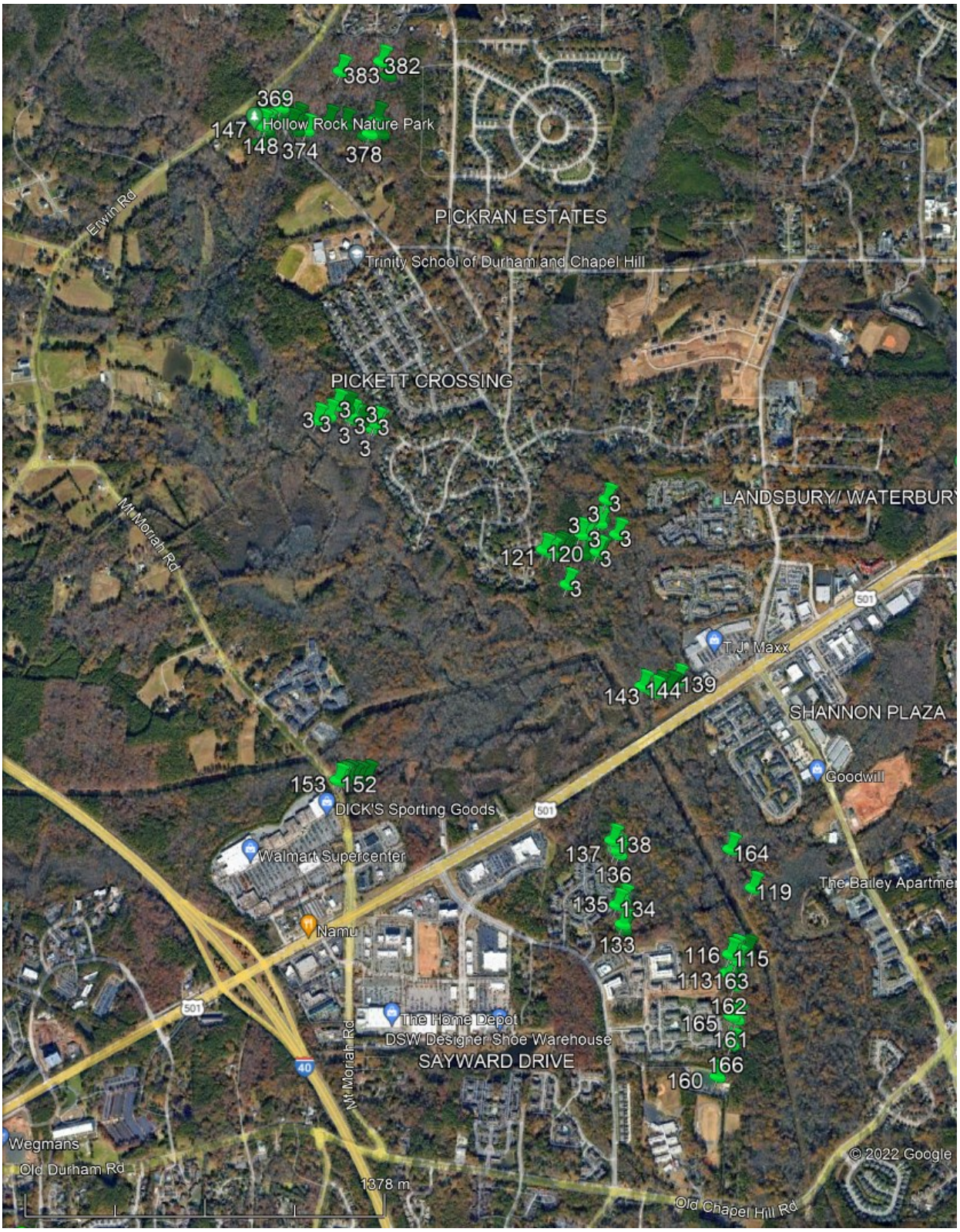
References

Brinda, JC & Atwood JJ. 2022. https://www.bryonames.org/.

Cenci, RM. 2000. The Use of Aquatic Moss (Fontinalis antipyretica) as Monitor of Contamination in Standing and Running Waters: Limits and Advantages. Journal of Limnology 60(1s):53-61.

Wichmann, B.L. and M.L. Wojcik. 2022. Natural Heritage Program List of the Rare Plant Species of North Carolina. North Carolina Natural Heritage Program, Division of Land and Water Stewardship, Department of Natural and Cultural Resources, Raleigh.

Figure 1. Map of bryophyte collection sites in the New Hope Creek Corridor (including historical locations).



Vascular Plants

Biology and Characteristics

Vascular plants include both the familiar seed-producing species, such as the flowering plants and conifers, and the more primitive spore-producing ferns and clubmosses. All possess specialized vascular tissues for moving water and nutrients up from the roots to the leaves and reproductive structures of the plants and to move the carbohydrates produced by photosynthesis throughout the plant. These structures allow vascular plants to reach great size – they include the largest organisms on the planet – and are responsible for the dominance of this taxon in all terrestrial ecosystems. As such, they received a great deal of scientific study, as is evident in the details covered in the following summary.

Species names follow the nomenclature used by Weakley (2022), as adopted in the Vascular Plants of North Carolina website (LeGrand, Sorrie, and Howard, 2022).

Survey Efforts

NEW HOPE BOTTOMLANDS: An intensive plant survey was made in the bottomlands north of Old Chapel Hill Road by Harry LeGrand and Jim and Liz Pullman on 1998-11-01, adding to records made on previous visits by the Pullmans in the spring of 1994 and 1995 and even earlier in the 1970s and 80s (LeGrand, 1999, described under US 15-501 Bottomlands). More recently, a survey was conducted in this area by Rickie White and Milo Pyne in 2020 and 2021 (White and Pyne, 2021). Site visits during that survey included a trip made 31 July 2020 and on subsequent days during that summer by M. Pyne, B. Wichmann, K. Gianopolos. A survey of the spring flora was also made by White and Pyne on 21 May 2021. During the current project, an initial trip was made by Bruce Sorrie and Harry LeGrand on 2021-09-02, and a survey of the spring flora was made by LeGrand on 2022-03-18 and 2022-04-22. Incidental records were made during the survey by various members of the NCBP and a few more records were extracted from the GBIF database, mainly observations originally submitted to iNaturalist (GBIF.org (12 September 2022) GBIF Occurrence Download https://doi.org/10.15468/dl.xbsf3m).

HOLLOW ROCK NATURE PARK: Steve Hall made reconnaissance visits to this site in 2005, listing some of the more conspicuous plant species in addition to describing the ecological quality of the natural communities (Hall, 2005). A much more intensive survey was made during the current project, with site visits made by LeGrand on 2021-09-13 and 2022-03-18, and by Hall on 2022-10-23. Additional records from this popular park were obtained from the GBIF database.

MT. MORIAH BOTTOMLANDS: Systematic surveys for vascular plants have not yet been conducted in the portion of the study area located between Hollow Rock Nature Park and the New Hope Bottomlands. Trips were made by Steve Hall on 2022-06-09 and 2022-07-19 to document the presence of *Carya laciniosa* in that area and in addition to that species, a few records were made of other species associated with rich, alluvial soils. A few additional records

were extracted from the GBIF database, but this area lacks a trail system and is rarely visited by the public.

MUD CREEK BOTTOMLANDS: This site was not surveyed for plants during the present inventory or in previous surveys.

Summary of the Plant Species Recorded During the Project

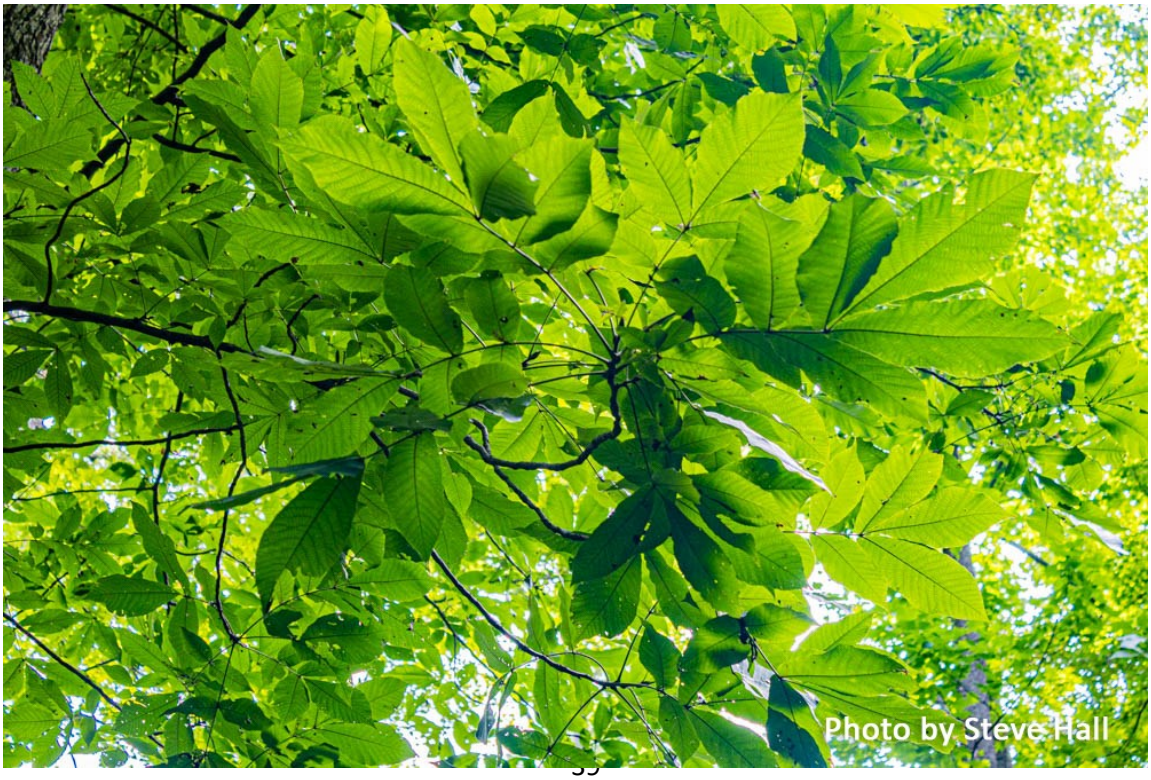
A total of 443 species of vascular plants (listed in the project website) have been identified within the overall area between Erwin Road and the upper end of the Wildlife Sub-impoundment on NC 54 (see Map 1). The current survey, which covered only the portion of this area north of Old Chapel Hill Road, documented 327 species, 125 of which were recorded for the first time during this inventory. The complete list is given in Appendix 5.

Noteworthy Species

Nine species on the NHP Significantly Rare or Watch Lists (Wichmann, 2021) have been recorded in the project area. Two of these species, Big Shellbark Hickory and White-nymph, are among the rarest species in North Carolina and have vigorous populations within the study area. Two others, Dense-Flower Smartweed and Lewis's Heartleaf, were recorded in this area for the first time during the current survey.

S1 Species

BIG SHELLBARK HICKORY (*Carya laciniosa*), was first recorded in the New Hope Creek floodplain by Harry LeGrand (LeGrand, 1999). Now known to be extant only along the Roanoke River and New Hope Creek (LeGrand, Sorrie, and Howard; accessed 2022-09-10), it is ranked as S1 by the



Natural Heritage Program and is listed as Threatened by the North Carolina Plant Conservation Program (Wichmann, 2021). The occurrence of this species on the north side of US 15-501 was first documented during the current survey.

WHITE-NYMPH (*Trepocarpus aethusae*) was first discovered in the state in the New Hope floodplain in a vegetation survey conducted by Rickie White and Milo Pyne (White and Pine, 2021). This is the only known population of this primarily Gulf Coast and Mississippi Valley species north of South Carolina (LeGrand and Sorrie, accessed 2022-07-30). Like the Big Shellbark Hickory, this species is ranked as S1 by the Natural Heritage Program (Wichmann, 2021). So far, this species has only been found in the floodplain between US 15-501 and Old Chapel Hill Road. With this extremely narrow distribution, this species has one of the most restricted ranges of any species in any taxonomic group in North Carolina.

At least one other S1 plant species, Cherokee Sedge (*Carex cherokeensis*) has been recorded in the New Hope floodplain, but well downstream of the current study area in the vicinity of one of the subimpoundments near Stagecoach Road. This record was made by C. Rothfels et al. on 30 April 2009, but we did not become aware of it until after field work for the New Hope survey had been completed. Consequently, we did not make a special effort to look for it and it will need to be a high priority in any future surveys conducted in the area.

S2 Species

ATLANTIC ISOPYRUM (*Enemion biternatum*) is state ranked as S2 and listed as a Species of Special Concern (Wichmann, 2021). It has been reported from the study area but was considered to be possibly extirpated by LeGrand (1999). It was not rediscovered during the current inventory.

SENECA SNAKEROOT **(***Polygala senega*) is state listed as S2 and considered to be of Special Concern in North Carolina. This species was observed by Rob Sutter and Liz and Jim Pullman during a site visit in the 1980s (Hall et al. 1999), probably on slopes located adjoining the floodplain in the area south of Old Chapel Hill Road. It was not observed during the current survey.

S3 Species

DENSE-FLOWER SMARTWEED (*Persicaria densiflora*), state-ranked as S3 and placed on the Natural Heritage Program Watch List, was found growing along the outer edge of the New Hope Bottomlands on a visit made by LeGrand and Sorrie during this project on 2021-09-02. This species is associated with both swamp forests and marshes and is considered rare and local in the Coastal Plain and very rare in the lower Piedmont (LeGrand, Sorrie, and Howard; accessed 2022-09-10).

DWARF GINSENG (*Nanopanax trifolius*), state-ranked as S3 and included on the NHP Watch List, has been recorded at a single site within the New Hope floodplain where it is considered still extant. That site, however, is located south of Old Chapel Hill Road, which is outside of the area surveyed in the current study. Although we targeted this species for searches during its flowering period, none were found in the surveyed portion of the floodplain (we did not search for it at its originally known site).

GODFREY'S THOROUGHWORT (*Eupatorium godfreyanum*) is state-ranked as S3 and placed on the Natural Heritage Program Watch List.

LEWIS'S HEARTLEAF (*Hexastylis lewisii*), state-ranked as S3 and placed on the Natural Heritage Program Watch List, was documented during the current survey on 2022-03-18 by Harry LeGrand at the Hollow Rock Nature Park. This record appears to be the first for this species within the project area.

SOUTHERN REIN ORCHID **(***Platanthera flava var. flava*), ranked as S3 by LeGrand, Sorrie, and Howard (accessed 2022-09-10) but is not included on the Rare Plant List by NHP (the species is listed as W6, indicating rarity within some regions of the state). This species was recorded in the New Hope Bottomlands in the 1990s (Hall et al., 1999) but was not found in the current survey.

SOUTHERN SHAGBARK HICKORY (*Carya carolinae-septentrionalis*) is state ranked as S3 by LeGrand, Sorrie, and Howard (accessed 2022-09-10) but is not included on the NHP Rare Plant List.

YELLOW TROUT-LILY (*Erythronium americanum*) is ranked as S3 by LeGrand, Sorrie, and Howard (accessed 2022-09-10) but is not included on the NHP Rare Plant List.

Overall Vegetation Quality

The New Hope Bottomlands are currently ranked as having Exceptional Quality by the North Carolina Natural Heritage Program, based both on its possession of the rare plants described above and the overall maturity and quality of its natural communities. Although strands of barbed wire imbedded in tree-trunks (S. Hall, pers. obs.) indicate that some use was made of this tract historically for pasturing livestock, the frequent floods and extensive wetlands of this area have protected it from major episodes of habitat conversion. From the aerial photos of this area dating back to 1940 (see Figures 3 and 4, New Hope Biodiversity Survey Website), most of this area has been forested for at least the past 82 years, with the southern two-thirds probably supporting a mature stand of hardwoods possibly dating back a further 70 to 100 years based on the dominance of hardwoods evident in the 1940 photograph. The only major impact to this stand over the past century appears to have been the construction of a powerline corridor (visible in the 1972 aerial photo), running through the center of the floodplain.

Although located along a smaller stream and with a much narrower floodplain, the stand of bottomland hardwoods located within the New Hope Bottomlands (south of US 15-501) is quite comparable in quality to stands located along the Roanoke and Tar, two large brownwater rivers noted for the high pH and nutrient richness of their alluvial soils. The Buzzard Point Floodplain Forests on the Roanoke River are particularly similar. They possess the only other populations of Big Shellbark Hickory occurring in North Carolina and the stand overall is similar in maturity: as in the New Hope Bottomlands, many trees are two feet in dbh and there are at least some that are at least three feet in dbh (LeGrand and Hall, Site Survey Report, August 22, 2012). If anything, however, there appear to be more Shellbark Hickories at the New Hope Bottomlands and the state champion Shellbark is also located there. While Buzzard Point has some species that are missing from the New Hope Bottomlands, including such rare species as Heartleaf Nettle (S2), Catchfly Cutgrass (S2?), and Pursh's Wild-petunia (S2), the New Hope Bottomlands possess the state's only known population of White-nymph (S1). Overall, the herb layer of the New Hope Bottomlands appears to be much richer, with species such as Reflexed Wild-ginger, Smooth Yellow Violet, Yellow Trout-lily, and Spreading Chervil covering large areas of the floodplain.

The Mt. Moriah Bottomlands were separated from the New Hope Bottomlands by the construction of US 15-501 in 1953. Unlike the New Hope Bottomlands, which largely survived as an intact block through much of the last century, the bottomlands located between Erwin Road and US 15-501 consisted largely of a patchwork of pastures and cultivated fields with an interspersed scattering of forest lands. As shown in a series of historic aerial photos (available online at https://maps.durhamnc.gov/), some of the tracts that have been acquired by Durham County for conservation were still open as late as 1994. By 1999, however, all of these fields can be seen to be succeeding to forest.

While it will take time for some of these tracts to reach the level of maturity found in the New Hope Bottomlands, the tract of forest immediately north of US 15-501 is already in good condition and the portion of that tract within the floodplain of New Hope Creek supports a number of the species associated with the rich alluvial soils on the south side of the highway. These include at least a few Big Shellbark Hickories, as documented in the current survey.

The floodplain of Mud Creek, on the other hand, did not appear to have any Shellbarks or other species associated with rich soils, although the stand located just north of US 15-501 in this drainage is otherwise in good condition. Apart from a few stands of Loblolly Pines, this tract of mature hardwoods extends all the way north to the Mud Creek Bottomlands. A detailed survey of the Vascular Plants of this area, however, still needs to be performed.

The upland habitats located in the Hollow Rock Nature Park have received less attention from biologists than the bottomlands along New Hope Creek and are currently unranked by the Natural Heritage Program. However, this area also appears to be covered by forest since at least 1940 (see Figure 3 in the New Hope Project website) and the ridge on the east side of Pickett Road, in particular, seems to have supported a stand of mixed hardwoods and Shortleaf Pines since that time. White Oak is the dominant species in that area, but a number of other species associated with dry-oak hickory forests are also present, including small numbers of Post Oak and Blackjack Oak. Some mafic influence appears to exist based on the presence of Southern Shagbark Hickory, Biltmore Ash, Florida Maple, Eastern Redbud, and Hop-hornbeam. Trees with diameters of 15” are common and at least one Southern Red Oak was found with a diameter of 30”. Currently, that area is in excellent condition and supports the only population of Lewis’s Heartleaf (on the NHP Watchlist) documented for this area.

Changes in Composition over the Past Thirty Years

The New Hope Bottomlands was a site included in plant surveys conducted in the 1990s (Hall et al., 1999; LeGrand, 1999). A comparison of the species recorded during that period and those found during the current survey provides information on changes that have occurred in this ecosystem over the past thirty years.

The following eleven species were recorded at this site in the 1990s but were not found in either the current survey or the 2021 survey conducted by White and Pyne:

SNAME	Habitat
Chaerophyllum tainturieri	Disturbed habitats
Asplenium platyneuron	Mesic slopes
Sceptridium biternatum	General forests
Goodyera pubescens	General forests
Viola affinis	General Wet Hardwood Forests
Persicaria punctata	Wetlands

SNAME	Habitat
Platanthera flava	General Broadleaf Herbaceous Mires
Cypripedium parviflorum	Rich Wet-Mesic Hardwood Forests
Anchistea virginica	Wetlands, mainly in the Coastal Plain
Cardamine angustata	Rich Wet-Mesic Hardwood Forests
Hypericum nudiflorum	Rich Wet Hardwood Forests

The first four species on this list may have been previously recorded on the slopes adjoining our project area, which we did not cover in any detail in the current project. *Viola affinis* could easily have been overlooked; purple-flowered violets were abundant in the study area but were not identified to species. *Persicaria punctata* is another species that may simply have been overlooked due to similarity to other members of its genus.

The same cannot be said for either *Platanthera flava* or *Cypripedium parviflorum*, both of which are unmistakable and were specifically targeted in the survey. While it is possible that they still exist within the study area – only a portion of which was directly surveyed during their flowering period – both of these species are known to be vulnerable to over browsing by deer. Their disappearance, thus, may in fact be due to the enormous increase in the state's deer herd over the past several decades, representing a real decline in the quality of the New Hope Bottomlands. On the other hand, these species are also known for lying dormant underground during certain years and it will take surveys conducted over a number of years to determine whether they are actually gone from the study area.

The final three species on the list of missing species are not considered to be palatable to deer and we have no explanation for why they would no longer be present within the project area. Again, additional surveys will be necessary to determine whether they have, in fact, actually disappeared from the area.

While only a few species are missing from the current survey that were previously documented in the study area, 223 species have been added to the species list since 2000. Many of these species are likely to have been present but overlooked in the earlier surveys, but at least some may have colonized the area since the first surveys were done. In some cases, the addition of these species represents a positive increase in the biodiversity of the project area. These include native species associated with beaver ponds, marshes, or other open wetlands, whose habitats have been developing since the powerline corridor was constructed in the 1970s and since beavers returned to the area in the 1980s. Forty-five of the newly added species are, in fact, associated with just such habitats. In these cases, their addition represents a return to conditions that once existed throughout eastern North America prior to the great extirpation of beavers – and the habitats they create – at the end of the 19th Century. These species are listed below:

Scientific Name	Common Name
Alisma subcordatum	American Water-plantain
Allium canadense	Meadow Garlic
Bidens aristosa	Bearded Beggarticks
Callitriche heterophylla	Two-headed Water-starwort
Carex crinita	Fringed Sedge
Carex intumescens	Bladder Sedge
Carex lupulina	Hop Sedge
Carex stipata	Awl-fruit Sedge
Carex vulpinoidea	Fox Sedge
Chelone glabra	White Turtlehead
Conoclinium coelestinum	Blue Mistflower
Cyperus strigosus	Straw-colored Flatsedge
Dichanthelium scoparium	Velvet Witchgrass
Diodia virginiana	Virginia Buttonweed
Glyceria septentrionalis	Floating Mannagrass
Glyceria striata	Fowl Mannagrass
Gratiola virginiana	Roundfruit Hedge-hyssop
Hydrolea quadrivalvis	Waterpod
Juncus coriaceus	Leathery Rush
Juncus effusus	Soft Rush
Lindernia dubia	Yellowseed False-pimpernel
Lobelia cardinalis	Cardinal-flower
Lobelia siphilitica	Great Blue Lobelia
Ludwigia alternifolia	Bushy Seedbox
Ludwigia palustris	Marsh Seedbox
Lycopus virginicus	Virginia Bugleweed
Mikania scandens	Climbing Hempweed
Mimulus alatus	Sharpwing Monkey-flower
Persicaria densiflora	Dense-flower Smartweed
Persicaria hydropiperoides	Swamp Smartweed
Persicaria sagittata	Arrowleaf Tearthumb
Pilea pumila	Canadian Clearweed
Pluchea camphorata	Camphor Pluchea
Pontederia cordata	Pickerelweed

Scientific Name	Common Name
Rhexia mariana	Maryland Meadow-beauty
Rhynchospora corniculata	Short-bristle Horned Beaksedge
Sagittaria latifolia	Broadleaf Arrowhead
Samolus parviflorus	Seaside Brookweed
Scirpus cyperinus	Woolgrass Bulrush
Scirpus georgianus	Georgia Bulrush
Spirodela polyrhiza	Greater Duckweed
Symphyotrichum lateriflorum	Calico Aster
Typha latifolia	Broadleaf Cattail
Verbesina alternifolia	Wingstem
Vernonia noveboracensis	New York Ironweed

On the other hand, an even larger number of newly recorded species are indicative of adverse changes to the environment: 55 species of invasive exotics. Only nine such species were documented prior to 2000, including such well known species as Japanese Honeysuckle (*Lonicera japonica*), Chinese Privet (*Ligustrum sinense*), and Japanese Stilt Grass (*Microstegium vimineum*). At least two that appear to be first documented in the state as invasives during the period covered by this survey, Alligator Flag (*Thalia dealbata*) and Lilyturf (*Liriope* species).

Conservation Concerns

Currently, the most significant threats to the native plant species of the New Hope Creek ecosystems come from the introduction of exotic species, including both plants as well as other taxa. These are species that are well-adapted to habitats located elsewhere on the planet, where they have a number of co-evolved relationships with other species that limit their impacts or keep their numbers under control. When transported into habitats where they have no long history of co-evolution, they typically act as destabilizing forces.

In the New Hope Bottomlands, the most obvious impact of an invasive species is the massive destruction of Ash trees (*Fraxinus* species) caused by a tiny, exotic beetle, the Emerald Ash Borer (*Agrilus planipennis).* In its native East Asian hardwood forests, the Ash species are able to survive the feeding activities of the larvae and there are a number of highly specialized predators – mainly parasitoid wasps – that act to control outbreaks of this species. In the exotic environments of Eastern North America where it now finds itself, the native Ash species – all seven species recorded in North Carolina -- are killed within just a few years of the larvae's feeding on the phloem layer below the bark and there do not appear to be any predators or pathogens that are standing in its way of spreading across all Ash-containing forests on the continent (they have recently shown up on the West Coast in Oregon – see USDA-APHIS, 2022).

In the New Hope floodplain, the main species attacked is the Green Ash (*Fraxinus pennsylvanicus*), a major canopy species of brownwater bottomland forests. Since the beetle arrived in North Carolina sometime around 2012, it has been spreading steadily across the state, its attacks becoming obvious in the Triangle area by 2019, showing up in both Duke Forest as well as the suburbs of Chapel Hill and Carrboro (S. Hall pers. obs.).

Within the area covered by the current survey, almost all mature trees have now been killed and are in the process of toppling to the ground following any wind storm. In the process, they are taking down other trees along with them and the openings they create are providing colonization sites for other invasive species, particularly Japanese Stilt Grass and Chinese Privet (see below). Within the next couple of years, virtually no mature trees are likely to be present in the stand. Although saplings of Green Ash are still fairly common, no further reproduction is likely to take place unless the Emerald Ash Borer ceases to be a major source of mortality before those young trees reach maturity and become vulnerable to the beetle's devastation.

In addition to destroying the Ash species themselves, a significant number of species closely associated with Ashes and Fringetrees (which is also attacked by the EAB) are likely to become extirpated. Impacts to a large number of insects and several fungi species will be discussed under summaries of their respective taxa.

Two other invasive species that are attacking plant species in the New Hope Bottomlands were discovered during the course of the current inventory. In 2021, wilting Spicebushes were found along one section of the Loop Trail in the New Hope Bottomlands. Specimens collected by S. Hall, H. Van T. Cotter of the NCBP and Mike Munster of the Plant Disease and Insect Clinic (NCSU Extension Service) were determined to be infected by an exotic fungus, tentatively identified as a species of *Ceratobasidium.* Although the exact identity of this species has yet to be determined (pers. comm. from Marc Cubeta, NCSU, to Van Cotter, 2022-10-09), infestations of several species of plants, belonging to several different families and including nursery stock, have implicated this fungus.

In a return visit made by Hall and Munster on 2022-09-15 to look for any spread of the infestation, no spread was observed to other Spicebushes (although one of the originally sampled plants was now completely dead), but a number of Pawpaws (*Asimina triloba*) and Greenbriers (*Smilax* species) were observed to be wilting in the same general area of the bottomlands. Samples taken from these plants, however, were determined to be attacked by an exotic species of beetle, the Black Twig Borer (*Xylosandrus compactus*). This Southeast Asian species was first detected in North America in Florida in 1941 and it has now spread up the coast as far as North Carolina (Dixon and Woodruff, 1983, updated in 2021). This is another minute species that bores into the stems of a wide range of woody plants, infecting them with an ambrosial fungus – usually *Fusarium solani* (not yet diagnosed in the New Hope samples) – which provides the actual food used by the beetle larvae. So far, the depredations by this species do not appear to be as extreme as caused by the Laurel Ambrosia Beetle in its attacks in the Coastal Plain on Red-bays and other members of the Lauraceae. However, if it causes

significant mortality just to Pawpaws or Greenbriers, it could drastically alter the shrub and vine layers of the New Hope Bottomlands. Since it is also known to commonly infect Red Maples, it could have important impacts on the canopy as well. The status of this species therefore needs to be carefully monitored.

Other invasive plant-feeding insects that have been documented in North Carolina and that are likely to arrive in our area in the near future include the Laurel Ambrosia Beetle, Spotted Lanternfly, and Walnut Twig Beetle (see (https://wakeaudubon.org/three-major-invasive-species-threaten-north-carolina-forests/). The insect surveys conducted in this inventory, however, did not discover any other significant exotic pest species; the moths, orthoptera, and hemipteran species surveyed in the inventory were nearly all native species whose interactions with their plant hosts is based on long co-evolved relationships, the opposite of the situations involving exotic, invasive species.

One exotic moth that we did document is worth mentioning in this context, however. Several individuals of the Alligatorweed Moth (*Macrorrhinia endonephele* = *Arcola* or *Vogtia malloi*) were collected in the marshlands located under the powerline running through the center of the New Hope Bottomlands. This is a species specifically introduced into the Southeastern United States from South America in order to control Alligatorweed (*Alternanthera philoxeroides*), a highly invasive plant in wetland habitats. On the negative side, the presence of this moth could indicate that even though Alligatorweed was not documented in the current survey, it could lurk somewhere within the abundant wetlands found at this site. Alternatively, it could indicate that the moth has shifted hosts to include some native plant species. On the other hand, its presence could simply indicate that it is doing a good job of suppressing an otherwise very aggressive invasive plant. The use of such biological controls is, in fact, the main hope of combating many of the invasive species now destabilizing our native ecosystems, including the Emerald Ash Borer.

Apart from the impacts of exotic, invasive insect species, one other herbivore-plant interaction needs to be mentioned: that between a greatly expanded deer herd and the native plants upon which it feeds. Over the past thirty years, the population of White-tailed Deer (*Odocoileus virginianus*) – a native species – has greatly benefited from the loss of its natural predators, e.g., Gray and Red Wolves and Mountain Lions, as well as its invasion of residential areas as safe havens from human hunters. As mentioned above, over-browsing by deer is having impacts on many native plants, including Orchids, such as the Yellow Ladyslipper. One other species belonging to the New Hope flora that may have been drastically affected by deer is Downy Arrowwood (*Viburnum rafinesquianum*). Although this species was observed during the current inventory, virtually all of the individuals seen were less than a foot high, rather than forming dense thickets of four-five tall foot-tall shrubs that once were commonly present in this area.

In general, however, the bottomlands on the south side of US 15-501 do not show the heavy impacts of deer over-browsing found in other bottomland habitats in the vicinity, such as the Big Oak Woods at Mason Farm or the Meadow Flats area of the Blackwood Division of Duke

Forest; the shrub and herb layers of the New Hope Bottomlands are still in good condition compared to those sites. This may be due to the fact that much of this tract is part of a state game land, where bow-hunting for deer is permitted. The Mt. Moriah Bottomlands, on the other hand, is not open for hunting and evidence of deer over-browsing is much more evident, including some areas along the rich bottomlands adjacent to New Hope Creek (S. Hall, pers. obs.).

As mentioned previously, a large number of exotic, invasive plant species were recorded during the current survey. These are listed below, along with their estimated severity of impacts to native vegetation, following designations by the North Carolina Native Plant Society (2010):

SNAME	Severity Rating
Ailanthus altissima	Severe Threat
Albizia julibrissin	Severe Threat
Elaeagnus umbellata	Severe Threat
Hedera helix	Severe Threat
Lespedeza bicolor	Severe Threat
Lespedeza cuneata	Severe Threat
Ligustrum sinense	Severe Threat
Lonicera japonica	Severe Threat
Microstegium vimineum	Severe Threat
Murdannia keisak	Severe Threat
Paulownia tomentosa	Severe Threat
Rosa multiflora	Severe Threat
Berberis thunbergii	Significant Threat
Broussonetia papyrifera	Significant Threat
Clematis terniflora	Significant Threat
Euonymus fortunei	Significant Threat
Ficaria verna	Significant Threat
Glechoma hederacea	Significant Threat
Humulus japonicus	Significant Threat
Lamium purpureum	Significant Threat
Ligustrum japonicum	Significant Threat
Lonicera maackii	Significant Threat
Lythrum salicaria	Significant Threat
Persicaria longiseta	Significant Threat
Persicaria maculosa	Significant Threat
Stellaria media	Significant Threat
Vinca minor	Significant Threat
Youngia japonica	Significant Threat
Ajuga reptans	Lesser Threat

SNAME	Severity Rating
Allium vineale	Lesser Threat
Artemisia vulgaris	Lesser Threat
Bromus secalinus	Lesser Threat
Cirsium vulgare	Lesser Threat
Daucus carota	Lesser Threat
Kummerowia stipulacea	Lesser Threat
Perilla frutescens	Lesser Threat
Elaeagnus pungens	Watch List B
Cardamine hirsuta	
Commelina communis	
Commelina diffusa	
Cynodon dactylon	
Digitaria sanguinalis	
Dioscorea polystachya	
Hemerocallis species	
Hypochaeris radicata	
Ilex cornuta	
Iris pseudacorus	
Lamium amplexicaule	
Leucanthemum vulgare	
Liriope unidentified species	
Mahonia bealei	
Oenothera speciosa	
Paspalum dilatatum	
Paspalum notatum	
Ranunculus parviflorus	
Rumex conglomeratus	
Rumex crispus	
Sida rhombifolia	
Spiraea thunbergii	
Thalia dealbata	
Trifolium pratense	
Trifolium repens	
Verbena brasiliensis	
Veronica persica	
Veronica serpyllifolia	

Two of these species that have had particularly devastating impacts to bottomland ecosystems are Chinese Privet (*Ligustrum sinense*) and Japanese Stilt Grass (*Microstegium vimineum*). These are species that can swamp the shrub and ground cover layers of bottomland forests, outcompeting native species belonging to those layers and inhibiting or preventing the

establishment and growth of tree species. These may be an especial threat to White-nymph and other low-growing herbaceous species. Large portions of the former pasturelands located within the Mt. Moriah Bottomlands are, in fact covered with dense growths of these species. Of particular concern for the New Hope Bottomlands is that they may also take advantage of the openings being created in the canopy due to the destruction of Green Ash by the Emerald Ash Borer. Lesser Celandine (*Ficaria verna*) is also seen as an emerging threat to bottomland habitats and is currently receiving substantial efforts to control its spread in the New Hope Creek watershed (see https://dukeforest.duke.edu/2020/04/03/duke-forests-least-wanted-fig-buttercup-ficaria-verna/).

The impacts of exotic invasives on natural ecosystems generally results from human-mediated transport – sometimes inadvertent – of species from their native ecosystems to ones to which the species and the ecosystems are mutually alien. Human activities can also be much more deliberate in their impacts to native ecosystems. This is true in the case of habitat conversion and in some cases, the use of chemicals to maintain the species composition in a particular state. Within the project area, a powerline right-of-way bisects the entire length of the New Hope Bottomlands and the southern portion of the Mt. Moriah Bottomlands. Although representing only a relatively small fraction of the overall acreage within the bottomlands, it creates a very long edge that allows both physical disturbances, such as increased light and heat and winds, as well as biological disturbances, such as the entry into the forest by weedy species, including a substantial number of the exotic invasives listed in the table above.

Although the open right-of-way also creates conditions favorable for the development of marshes, which are a natural component of floodplain ecosystems, the chemicals used to suppress woody growth beneath the powerlines appear to be affecting the development of these habitats. In addition to eliminating willows, which could pose a threat to the powerlines, the spraying is also affecting such low-growing shrubs as Buttonbush and even such prominent marshland species as Cattails (known to be sensitive to Glyphosates), which are nearly absent from the powerline corridor.

Currently, the impacts listed above – particularly those caused by invasive, exotic species – pose the greatest risk to the integrity of the floodplain vegetation. Those impacts may be dwarfed in the future, however, by those associated with climate change. There is already a detectable increase in the number of flood events (discussed in greater detail in the summaries for other taxonomic groups), but prolonged droughts, heat-waves, and the wild-fires that may result from those conditions could eventually completely alter the nature of the vegetation in this floodplain. In making recommendations to conserve the natural features of this ecosystem, both the current threats as well as those that can be predicted in the future, need to be considered.

Conservation Recommendations

Several recommendations can be made with respect to conserving the vascular plants within the project area; more general recommendations for conserving the entire ecosystem will be made at the end of this report.

1. Protect the entire populations of the White-nymphs and Big Shellbark Hickories. Although portions of the populations of both species occur on lands currently owned either by the Federal Government or Durham County, a substantial number of both species occurs on privately-owned tracts and are, thus, potentially threatened by clear-cutting or other forms of habitat conversion. In addition to bringing those areas into permanent conservation – either through direct acquisition or conservation easements – protection of buffers and connectors should also be considered.
2. Join the program to release parasitoids that control the population of the Emerald Ash Borer. Protect at least a few mature Ash trees as seed sources through use of systemic insecticides.
3. Remove exotic invasives, particularly those that pose significant threats to the native vegetation. Hand clearance would be preferable.
4. Work with nurseries to eliminate exotic invasives from being sold. Prohibit the use of exotic invasive species of aquatic plants – e.g., *Thalia dealbata* and *Iris pseudacorus* – from being planted in stormwater detention ponds.
5. Educate adjoining landowners about the threats to the natural ecosystems of planting potentially invasive species or any plants that are favored for browsing by deer.
6. Remove plants infected by exotic pathogens. This should be done in coordination with the NC Forest Service, Department of Agriculture, and the Plant Disease and Insect Pest Clinic of the NCSU Extension Service.
7. Allow bow hunting of deer either throughout the project area or at least within the undeveloped portions of the Mt. Moriah Bottomlands.
8. Replace chemical treatment of the powerline right-of-way with mechanical clearance of woody species or use an herbicide that is more specific to woody species and that is not long-persistent in its effects. Leave any sites that support marsh vegetation untreated, allowing development of cattail beds and willow thickets. If necessary, any woody vegetation that develops on these sites can be kept under control by periodic trimming.

References:

Buckingham, G.R. 2002. Alligatorweed. In: Van Driesche, R., *et al.* (eds.), Biological Control of Invasive Plants in the Eastern United States, USDA Forest Service Publication FHTET-2002-04, 413 p. Available online at: https://www.invasive.org/biocontrol/1Alligatorweed.cfm

Dixon, W.N. and Woodruff, R.E., 1983 (updated in 2021). *The Black Twig Borer, Xylosandrus compactus (Eichhoff)(Coleoptera: Scolytidae)*. Featured Creatures, University of Florida, Div. of

Plant Industry, Entomology Circular 250. Available online at: https://entnemdept.ufl.edu/creatures/trees/black_twig_borer.htm

LeGrand, H., B. Sorrie, and T. Howard. 2022. *Vascular Plants of North Carolina* [Internet]. Raleigh (NC): North Carolina Biodiversity Project and North Carolina State Parks. Available from https://auth1.dpr.ncparks.gov/flora/index.php.

North Carolina Native Plant Society (M. Buchanan, compiler). 2010. Invasive Exotic Plants in NC., 2010. Available online at: https://ncwildflower.org/invasive-exotic-species-list/

USDA-APHIS, 2022. Emerald Ash Borer website. Available online at: https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/emerald-ash-borer

Myriapods

Biology and Characteristics

There is an astounding diversity of animals in the soil, leaf litter, and woody debris on the forest floor. The diversity and numbers of leaf litter inhabitants are good indicators of the quality of the soil and the diversity of microhabitats on a site. In addition, the leaf litter fauna, along with fungi, bacteria and other microorganisms, are key to nutrient cycling in the forest. Nutrients and minerals taken up by tree roots are stored in the leaves. When the leaves fall, they are broken down and decomposed by the soil and leaf litter organisms, returning the nutrients to the soil.

The leaf litter has layers from the dry surface leaves of this year's autumn, to the soft, moist, partially decomposed leaves from prior years, to the fully decomposed rich organic layer underneath. The larger burrowing animals help mix these layers by carrying the newer material down, and creating air spaces and pathways for smaller animals, fungi and microorganisms.

Myriapods are important components of leaf litter communities. Millipedes are largely detritivores and play an important role in leaf litter decomposition. For example, the American giant millipede (*Narceus americanus*) is common and conspicuous in southeastern forests. This large millipede grinds leaf matter into smaller bits and partially decomposes the material in its gut, making the bits more accessible to fungi and smaller animals. There may be thousands of these in an acre, and it is estimated that cumulatively, they can contribute two tons per acre per year of nutrient rich millipede manure to the forest soil. These and other millipedes were plentiful in the New Hope Creek study area, indicating healthy decomposition and nutrient cycling.

Centipedes are fast-moving predators and play a role in the complex food webs of the soil and leaf litter communities. Although superficially similar in appearance, Millipedes and Centipedes are not closely related. Other groups of tiny Myriapods, the Symphyla and Pauropoda, were not included in this survey.

Survey Efforts

Myriapods were collected on ten days in 2021 (including 4 dates prior to the official start of the New Hope Biodiversity Survey). These included samples taken in all four seasons. In 2022, they were collected on two days during the winter and one in the summer.

Sampling involved searching in downed logs and debris on the forest floor, sifting leaf litter by hand, and processing leaf litter samples in Berlese funnels. A night survey was conducted with a UV flashlight, which will cause some species to fluoresce.

All sampling was done by Carol Tingley.

Summary of the Myriapod Species Recorded During the Project

Nine species of Millipedes were identified in the survey and three species of Centipedes. Durham and the Triangle area have been fairly well surveyed because of the proximity to major universities and the NC Museum of Natural Sciences. Additional species of Myriapods are known to occur in the region and are likely present in the study area.

Noteworthy Species

Although not rare, *Aniulus orientalis* is not often encountered. Its distribution is limited to central North Carolina, southwestern Virginia, and southern West Virginia.

Overall Quality of the Litter Community; Comparison to Similar Sites

The leaf litter community seemed rich and well-developed. Flooding in the bottomlands is frequent enough to maintain moisture, at least in lower microhabitats, but in most places the flow is not strong enough to wash away the leaf litter. There are plenty of downed logs and debris to provide diverse microhabitats. *Narceus americana*, *Cleidogona major* and *Pseudopolydesmus serrata* were abundant.

Conservation Concerns

Like other habitats, leaf litter has its share of invasive species. Non-native millipedes, as well as native species, were present in the New Hope Bottomlands, which is not surprising since the study area is near an urban environment. *Ophyiulus pilosus*, native to Europe, and *Oxidus gracilis*, native to East Asia, are both present in the study area.

Leaf litter communities will be vulnerable to the warming and drying effects of climate change, since many of these species rely on cool and moist microhabitats. Although difficult to predict without more survey data, the loss of diversity within the leaf litter fauna is likely to have important effects on litter decomposition and soil nutrification, with adverse impacts to the rest of the ecosystem.

Arachnids

Biology and Characteristics

Arachnids are one of the major groups of the Arthropods, sharing a chitinous exoskeleton and jointed legs with the Crustacea, Myriapods, Insects, and other members of this phylum. They differ from other Arthropods in their lack of antennae and mandibles and their possession instead of pedipalps and chelicerae (external mouthparts). Most adults, at least, possess eight legs, separating them from Insects and other Hexapods, which have six, and from Crustaceans, which generally have ten or more.

Of all the Arthropods, Arachnids are undoubtedly the least appreciated by humans, who generally find them either frightening or repulsive. Some, in fact, have dangerous venom or other defenses and others – ticks and mites – are significant as mammalian parasites and can transmit serious diseases. The vast majority, however, are free-living species that occur in virtually all terrestrial (and at least a few freshwater) habitats on Earth. Mites are one of the most important groups of soil and leaf litter organisms and spiders are one of the largest and most ubiquitous groups of predatory species, feeding especially on insects.

Although playing critical roles in all of the ecosystems they inhabit, they have received only scarce attention in biodiversity surveys; many aspects of their life histories, distribution, abundance, and especially their conservation status are still poorly known. Compared to most of the other groups included in the New Hope Creek Biodiversity Survey, our inclusion of spiders, harvestmen, pseudoscorpions, and a very small number of mites represents what is still a pioneering effort.

Survey Efforts

The New Hope Creek bottomlands was surveyed for spiders using a variety of day and night monitoring techniques such as sweep nets, beat sheets, litter sifting, and visual surveys. Spider surveys were conducted by Carol Tingley, Brian Bockhahn, and John Petranka. Carol Tingley also contributed records for pseudoscorpions and harvestmen. Additionally, Tracy Feldman provided records for foliage-feeding mites and Steve Hall provided some of the records for Harvestmen.

Records were made on 62 different dates during and just prior to the beginning of the New Hope survey, including 42 dates in 2021, covering all months except February, and 20 dates in 2022, covering all months from January to August.

Summary of the Arachnid Species Recorded During the Project

A total of 137 species of Arachnids were documented in the survey, including seven harvestmen, four mites, four pseudoscorpions, and 122 spiders. A complete list of these species is given in Appendix 6.

Noteworthy Species and Special Features of the Arachnid Fauna

Upland sites, which were best represented in the study area at the Hollow Rock Nature Park, contain mostly dry soils, but the leaf litter there nonetheless provided ample finds including some state records. Wolf spiders in the family Lycosidae predominated in these habitats, including members of the genera *Hogna*, *Tigrosa*, *Rabida* and *Schizocosa*. These small to large spiders are the species that produce a silvery-white eye-shine in the leaf litter and tree trunks. Additional ground spiders include new county records for *Drassyllus ellipes*, and a few of the ant-mimic spiders in the genus *Castianeira*. Some tiny sheet web weavers living in the leaf litter include *Agyneta angulata*, *A. parva* and *A. micaria*, the latter being only the second record in the state for this species. In the same leaf litter habitat several new state records were obtained: two different dwarf spiders, *Anthrobia acuminata* and *Souessoula parva*, *Lathys immaculata*, a tiny mesh web weaver, *Maymena ambita*, a minute-clasping weaver and *Trebacosa marxi*, a wolf spider.


Tigrosa georgicola
Photo by Steve Hall

Rock outcrops along New Hope Creek – restricted to the Hollow Rock Park in the study area -- provided for some unusual habitat for the Piedmont. Large overhangs with many crevices and surrounding leaf litter hosted a variety of species including a very rare cave cobweb spider, *Eidmannella pallida* only known from a couple counties. An abundance of spiders from the genus *Phrurotimpus*, or Guardstone spiders were also found in this habitat. *Phrurotimpus annulatus* was new for Orange County. This family gets its name from the habit of laying their flat eggs sacs on the undersides of rocks, so are essentially only present in rocky areas and outcrops.

The riparian areas around New Hope Creek and its tributaries contained the expected species of fishing spiders, in the genera *Dolomedes* and *Pisaurina*. Abundance was average, probably owing to the many floods which disperse the spiders and their food. *Dolomedes tenebrosus*, the Dark Fishing Spider is one of the largest species in the state by leg span. Their presence indicates the existence of ample food sources around waterways, since among arthropods they are near the top of the food chain. A small jumping spider *Marpissa lineata*, was detected in both Orange and Durham County for new county records.

The floodplain areas contained an abundance of spiders and was one of the richest areas surveyed. Several species were found in exciting numbers, including a few species with few records for the Piedmont. Several colonies of *Hyptiotes cavatus*, the Triangle Web Weaver were

found in some of the fallen tree root masses. This tiny species is overlooked with only a handful of records in North Carolina. It has a nocturnal habit of building a small triangular web, then sitting in wait while pulling back on a single strand, before releasing it catapult-like on potential prey.

In the wettest portion of the floodplain, a single *Pisaurina brevipes*, a Nursery Web Spider was new for Durham County as well as the Piedmont. This species is uncommon and more typical of the coastal plain, and the habitat here allows them to colonize up the swampy floodplains from the coast. Another new county record and few for the state was *Trachelus similis*, a Broad-faced Sac Spider.

Edge and old field habitat are present in along the powerline that runs through the center of the New Hope Bottomlands, as well as along the trail bordering the western edge of the bottomlands, and a meadow at Hollow Rock Park, contained the expected species such as day active small orb weavers in the genus *Mangora*, several *Salticidae*, jumping spiders and the *Oxyopidae*, or Lynx spiders. Also found here were several *Neoscona* spiders often referred to as Halloween spiders, and *Metepeira labyrinthea*, the labyrinth orbweaver.

Found in a couple different habits was another good find and the only record for North Carolina, *Ghelna canadensis*, a tiny jumping spider.

Human habitations contained some of the more common “backyard” species, though in very low numbers. The highly manicured recreation sites provided little habitat for spiders or their food items.

Overall Quality of the Arachnid Community and Comparison to Other Sites

The diversity of spiders at this location was impressive, with representative species found in each habitat. Just as important, the abundance of spiders in these habitats appeared to be at or above the levels observed at comparable sites. Spiders thrive where there is an ample food source in flying or terrestrial invertebrates, so a diversity and abundance of spiders usually indicates the presence of a high diversity and abundance of food items.

Overall, the bottomlands along New Hope Creek possessed a high level of diversity and abundance of spiders, at levels equivalent to properly managed habitats in North Carolina, such as parks and refuges. The interior mature uplands, floodplain and riverine areas were extraordinary for all arachnids. Only the adjoining recreational portions of the property and boundary areas near houses provided little to no habitat for spiders. Habitat edges were average to below average, with little room for the spiders to disperse and colonize outward.

Conservation Concerns

No obvious sources of concern were found during the survey. This was somewhat surprising given the low diversity and abundance found in the macro-moth fauna, one of the most important food sources for spiders. Only slight evidence, if any, was found for the influence of flooding that appeared to be possibly affecting a number of the different animal groups included in this survey.

Conservation Recommendations

1. Continue to monitor species diversity and abundance of spiders and other Arachnids in the New Hope project area. Conduct quantitative surveys that can be compared across sites in order to determine what trends exist in the populations of this group of species.
2. Avoid the use of broad-spectrum insecticides to combat mosquito outbreaks or defoliating attacks of foliage-feeding insects.

Dragonflies and Damselflies (Order Odonata)

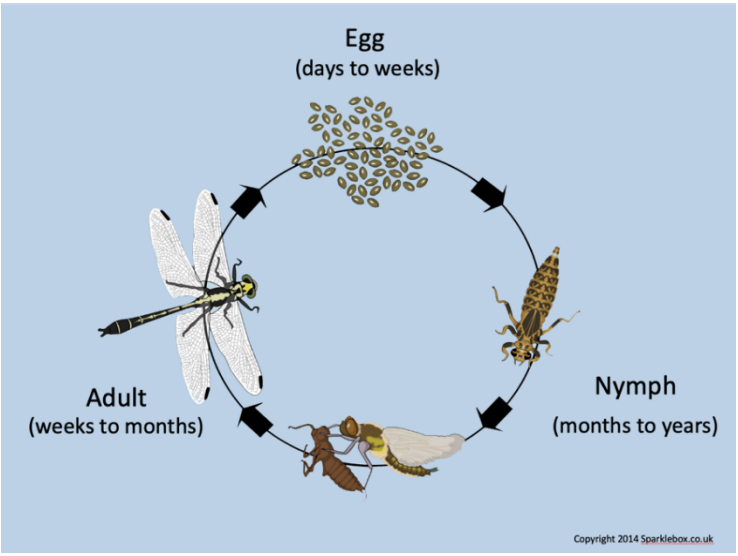
Introduction and Species Diversity

Dragonflies and damselflies belong to the ancient insect Order Odonata and are thus referred to as odonates (or, informally, as 'odes'). Odonates very similar to present-day species have

flown our skies for over 300 million years, surviving multiple mass extinctions and seeing the dinosaurs come and go. As of 2022, there are 6,383 known species worldwide (Paulson et al., 2022), of which 470 species occur in North America (Paulson, 2022). The Dragonflies and Damselflies of North Carolina website (LeGrand, H., et al., 2022) documents 189 species in North Carolina, with 115 species reported from Durham County and 105 from Orange County. Durham and Orange Counties have, respectively, the fifth and tenth highest numbers of recorded species among North Carolina's 100 counties.

Life History

The odonate life cycle is partly aquatic and consists of three stages: egg, nymph, and adult. Adult females will lay (oviposit) from several hundred to a thousand or more eggs. Eggs are deposited either directly in the water or inside of plant material that is in or near water. Females oviposit in a wide variety of habitats depending on the species. These include lakes and ponds, swamps, marshes, springs and seeps, and streams of all sizes and types. Embryos develop within the eggs



over a period of a few days to a few weeks and then emerge as predacious larvae (nymphs) that feed mostly on aquatic invertebrates. The nymphs grow in stages (instars) via a series of molts, with the final instar completing metamorphosis to emerge as the next generation of adults. The nymph stage is typically the longest, lasting from a few months up to one or two years (though in some species it may last for as long as three to five years). In piedmont North Carolina, most species probably produce one or two generations per year, though certain species might only produce a generation every two to three years.

The newly-emerged adults typically leave the breeding site for a few weeks in order to feed while they mature sexually. During this period, they may be found basking and feeding in open areas such as natural openings, powerline clearings, roadsides, and fields. Sexually mature males are the first to return to the breeding sites, where they engage other males in the dominance and territorial contests that so often attract our attention. A week or so after the males' arrival, females appear at the breeding sites to mate and lay eggs, thus completing the life cycle. The adult lifespan usually ranges from a few weeks to as long as two or three months. Adult odonates in the North Carolina Piedmont cannot survive winter temperatures, so species overwinter either as eggs/embryos or as nymphs. A handful of newly-emerged adults have been seen in Durham and Orange counties as early as late February, but most of our early-Spring fliers typically do not appear until the third or fourth week of March.

Survey Efforts and Species Totals

As with butterflies (noted above by Steve Hall), assessing adult odonate occurrence is relatively straightforward because of the adults' high visibility and conspicuous diurnal behavior. Opportunistic site visits of varying lengths were made nearly year-round on 74 dates between 7/3/21 and 9/13/22. Odonates were observed on 49 of the visits, with the earliest Spring sighting being made during the third week of March, and the latest Fall sighting during the third week of September (a few species likely persisted for several weeks beyond this date, but no site visits were made during November).

A total of 239 odonate observations were recorded during the study period (2021-2022). An additional 34 sightings from within the study area were recorded prior to 2021 and those were added to the survey tally, raising the observations total to 273. John Petranka contributed 232 records; Steve Hall (and parties) contributed 35; Harry LeGrand and party contributed 4 records, and Tracy Feldman 1 record. A complete list of the odonate records can be found at the New Hope Creek Biodiversity Survey 2021 - 2022 website (North Carolina Biodiversity Project, 2021). Open this link: https://auth1.dpr.ncparks.gov/ncbp_neho/search.php , then select "Odonates" from the taxon drop-down menu, and then click "Find".

Thirty-five species were found during the 2021-2022 survey period. Four more species had been documented previously within or adjacent to the survey area, bringing the overall odonate tally to 39 species (Table I). Twenty-two species were observed in Durham County

representing 22/115 or 19% of its known odonate fauna, and 35 species were found in Orange County, representing 35/105 or 33% of its odonate fauna.

Eight of North Carolina's ten odonate families are represented, with only the Petaltail dragonfly (family Petaluridae) and Spreadwing damselflies (family Lestidae) not seen. The Gray Petaltail (Tachopterix thoreyi) is a seep specialist, and its absence can be explained by the apparent paucity of seeps within the study area. Spreadwing damselflies generally prefer open ponds, lakes, and marshes with shoreline vegetation rather than the partially open habitats found in the survey area. Since Spreadwings are relatively inconspicuous, they might yet be found by carefully searching open marshy areas in the powerline clearings at Mount Moriah and New Hope Creek Bottomlands, or perhaps by searching the margins of partially open beaver ponds.

Search efforts differed between the three survey sites, and those differences most likely affected the number of species recorded per site (Table 1). The most intensive effort was made at Hollow Rock Nature Park where odonates were seen during 27 visits totaling 39 hours, with 32 species observed. At New Hope Bottomlands, 20 visits were made totaling approximately 12 hours, and yielding 17 species. Mount Moriah Bottomlands was surveyed twice for about 5 hours, with 11 species being found.

Hollow Rock Nature Park. Hollow Rock Nature Park is the most easily accessible of the three survey sites, with developed trails on both sides of Pickett Road that provide access to a number of odonate breeding and feeding habitats (Table 2). The highest species count of any survey site, 22, was made along New Hope Creek. Prominent species observed there include several stream-breeding species that were not found at any other survey sites, including Dragonhunter (*Hagenius brevistylus),* Black-shouldered Spinyleg (*Dromogomphus spinosus*), Prince Baskettail (*Epitheca princeps*), and Dusky Dancer (*Argia translata*).

The Meadow (20 spp.) and Pickett Road Edges (16 spp.) sites lack breeding habitat but are important maturation and feeding areas. For example, seven stream-breeding early Spring flyers were observed at Pickett Road only during the 2-3 weeks between 4/2/22 and 4/20/22: Ashy Clubtail (*Phanogomphus lividus*), Lancet Clubtail (*Phanogomphus exilis*), Common Baskettail (*Epitheca cynosura*), Stream Cruiser (*Didymops transversa*), Springtime Darner, (*Basiaeshna janata*), Twin-spotted Spiketail (*Cordulegaster maculata*), and Uhler's Sundragon (*Helocordulia uhleri*). Those species spent that relatively short period feeding and maturing sexually before moving on to their respective breeding habitats. Twin-spotted Spiketail (*Cordulegaster maculata*) and Uhler's Sundragon (*Helocordulia uhleri*) are species of conservation concern, and are discussed in greater detail below under Noteworthy Species.

The open feeding habitat at the Meadow site attracted several of the early Spring flyers mentioned above, as well as an assortment of widespread and common species such as Eastern Pondhawk (*Erythemis simplicicollis*), Common Whitetail (*Plathemis lydia*), and Common Green Darner (*Anax junius*). The only Calico Pennant (*Celithemis elisa*) seen during the survey also was found there, probably as a local stray since it is typically found at open ponds, lakes, etc. The most significant sighting at the Meadow subsite was a rare-to-uncommon Arrowhead Spiketail (*Cordulegaster obliqua*), which is discussed below under Noteworthy Species.

The lowest species diversity at Hollow Rock Nature Park was found east of Pickett Road at the Bottomland (2 spp.) and Dry Oak-Hickory Forest (3 spp.) stations, and west of Pickett Road along the Loop Trail (10 spp.). One of the two species found at the Bottomland station was the ubiquitous Common Whitetail (*Plathemis lydia*), but the second was the far less common Twin-spotted Spiketail (*Cordulegaster maculata*), which is discussed below in the Noteworthy Species section.

The Loop Trail west of Pickett Road borders New Hope Creek and then a beaver pond for most of its length, and the species seen there breed in those two habitats. All six of the species that were found at the beaver pond are common and widespread; five of them can be found in all 100 North Carolina counties, and the sixth in 98 of the 100 counties. A single Blue-fronted Dancer (*Argia apicalis*) was found along the Loop Trail just upslope from New Hope Creek. This species is widely distributed throughout North Carolina and can be quite common in the right habitat, but it generally prefers larger streams (such as the Eno River in Durham and Orange Counties). Though this individual may have been a non-breeding local stray, it is nonetheless the first record of a Blue-fronted Dancer from the New Hope Creek watershed.

Mount Moriah Bottomlands. Mount Moriah Bottomlands is perhaps the least accessible of the three principal survey sites, and surveying requires considerable bushwhacking in the absence of developed trails. The site was clearly under-sampled for odonates during the current survey, receiving just two visits that totaled about 5 hours, during which 11 species were observed.

Steve Hall recorded five additional species at this site in 1992 during an assessment of wildlife habitats, movement corridors, and rare animals in Durham County (Hall, S.,1995). His records included a Spangled Skimmer (*Libellula cyanea*), a species that was not seen in the current survey. In addition, Duncan Cuyler collected an Umber Shadowdragon (*Neurocordulia obsoleta*) at the site in 1960, bringing the overall site tally to 17 species. A few comments on assessing the presence of Umber Shadowdragons are found below under Noteworthy Species.

Given the lesser search effort and the fact that all 17 of the odonate sightings at Mount Moriah Bottomlands were made during June and July, there is little doubt that the species diversity at this site was underestimated. Further search efforts during Spring, late Summer, and early Fall are needed to fill in those gaps.

New Hope Creek Bottomlands. Odonates are generally encountered at open sunny sites, or else in sunny patches within shady sites. Given the dense forest canopy at New Hope Creek Bottomlands, it is not surprising that the highest odonate counts were at the two sunny powerline clearings along the Loop Trail (10 spp.), and along the Edge Trail, including its paved extension south towards Old Chapel Hill Road Park (10 spp.). The species seen at those two subsites are all widespread and common. Of some interest are the Wandering Gliders (*Pantala flavescens*) seen along the Edge Trail's paved extension on 8/4/21 and 8/5/21. Somewhat surprisingly, those were the only sightings of that species during the survey, and just the second documented locality for it in the New Hope Creek watershed (LeGrand, H., et al., 2022). Wandering Gliders occur world-wide, and as their name suggests, are renowned for their long-distance migrations (Troast, D., et al., 2016). In the North Carolina Piedmont they are regularly seen from July through mid-October, usually in modest numbers. However, in the early Autumn of certain years they can be found in larger numbers during southbound migrations, sometimes co-migrating with Common Green Darners.

The shadier sites at New Hope Bottomlands supported fewer species. The five species seen along the wooded sections of the Loop Trail included Ebony Jewelwing (*Calopteryx maculata*), Blue-tipped Dancer (*Argia tibialis*), and Common Whitetail (*Plathemis lydia*), all of which were encountered basking and feeding in sunny patches along the trail. Three common species were observed at flood channels and oxbow ponds, and were all seen to be engaging in breeding behaviors. Using flood channels and oxbow as breeding habitat can be risky, since they can be subject to both scouring floods and to drying. Finally, two male Cyrano Darners (*Nasiaeschna pentacantha*; NatureServe rank S4S5) were observed patrolling in their characteristic manner along a calm stretch of New Hope Creek adjacent to the east section of the Loop Trail.

Noteworthy Species

No new species were added to the odonate faunas for Durham County (115 spp.) or Orange County (105 spp.). The species counts for both counties have been relatively stable since 2000, with ten previously unrecorded species added to Orange County and five added to Durham County. This stability is due to the thorough collecting efforts of Durham native Duncan Cuyler

(1929-2010). He was the principal authority on North Carolina odonates for over four decades, having studied and collected them all across North Carolina. Frustratingly, over 950 of his Durham County specimens were labeled generically as “Durham, southwestern edge”, so we cannot say whether any of those were actually found within the current survey area.

Three species of conservation concern and one species represented by a single sixty-year-old record are of particular interest, and are discussed here.

Arrowhead Spiketail (*Cordulegaster obliqua*) has been assigned NatureServe rank of S3, indicating that it is considered to be rare or uncommon in North Carolina (LeGrand et al., 2022). Its NC range lies almost entirely within the Piedmont, where it breeds in small forested streams and seeps. On 6/16/22 a lone female (pictured) was found feeding at the edge of the meadow at Hollow Rock Nature Park (Orange County). A light coating of silt or mud on the distal half of its abdomen suggests that it had previously oviposited. Though a very short seep is located nearby to where it was seen, no seep specialists have been observed there. It may be more likely that this species breeds in larger seeps or small streams in nearby Duke Forest, or perhaps in one of the small headwater streams east of Pickett Road. Additional light could be shed on its breeding status by continuing to monitor for adults during its flight season (May and June), and by searching for nymphs in the nearby seep and in the small streams east of Pickett Road.

Uhler’s Sundragon (*Helocordulia uhleri*) is ranked by the NC Natural Heritage Program as S3S4, indicating that its status varies from being rare or uncommon in certain parts of its range and apparently secure in others (LeGrand et al., 2022). The editors of the Dragonflies and Damselflies of NC website now recommend a revised status of S3 due to a paucity of recent record submissions. Although it has been recorded at several localities on New Hope Creek just upstream of Erwin Road and at the Johnston Mill Preserve farther upstream, it is generally uncommon in the eastern Piedmont. Uhler’s Sundragon flies from late March to early June, with males making low patrols along the woodland streams where it breeds. Immature adults leave the breeding site to feed in clearings, as did the male pictured here,

which was found on 4/2/2022 along the sunny edges of Pickett Road at Hollow Rock Nature Preserve. Searches for males patrolling New Hope Creek from mid-March through May might help to clarify whether it breeds within the survey area or only uses it as feeding and maturation habitat.

Twin-spotted Spiketail (*Cordulegaster maculata*) is ranked by the NC Natural Heritage Program as S3S4, though the editors of the Dragonflies and Damselflies of NC website recommend a revised status of S4. This is a classic Spring-emerging dragonfly, flying from late March to late May, and breeding in clean streams of a variety of sizes and substrates. On 4/1/22, two exuviae (the nymphal exoskeleton left behind by the emerging adult) were found washed up on a bridge footing just upstream of the culvert passing under Pickett Road, confirming that this species breeds somewhere in the small streams east of Pickett Road. Three days later, an adult female was photographed nearby along the edge of Pickett Road. It would be interesting to search for breeding adults or nymphs within the survey area to exclude the possibility that the exuviae were merely washed downstream from Duke Forest.

Umber Shadowdragon (*Neurocordulia obsoleta*) is ranked by the NC Natural Heritage Program as S4, indicating that its populations are apparently secure in North Carolina. Why, then, has it been documented from Durham County on just five occasions since 1975? A clue lies in its common name, 'Shadowdragon'. Shadowdragons are crepuscular odonates, meaning that they typically fly, feed, and mate only after sunset, from twilight until dusk. During the day they hang motionless in streamside forests, where, given their drab coloration, they are particularly difficult to spot. Thus, a concerted netting effort in near-darkness is usually needed to capture and identify them. Fortunately, Duncan Cuyler was up to that challenge, having collecting 37 of the 42 Umber Shadowdragons reported from Durham County, including the 1960 record from the Mount Moriah Bottomlands. Cuyler collected two more individuals that same year from New Hope Creek at the concrete bridge in Duke Forest, so it may well be that this species, if searched for appropriately, will still be found within the survey area.

Comparison to Previous Results

Three species have been recorded from the study area previously that were not seen in the current survey: 1) an Umber Shadowdragon (*Neurocordulia obsoleta*) collected by Cuyler at Mount Moriah Bottomlands, as mentioned above; 2) a 1992 Spangled Skimmer (*Libellula cyanea*) record (Hall, 1995) from the Mount Moriah site; and, 3) a 2017 Powdered Dancer (*Argia moesta*) sighting from New Hope Creek in Hollow Rock Nature Park. A beaver dam constructed in recent years has submerged the formerly exposed rocks and shallow riffles preferred by this species. In addition, a 2016 record of a Blue Corporal (*Ladona deplanata*) seen at New Hope Creek just upstream from the survey area was included in the species tally, but none were seen in the current survey. Blue Corporals generally breed in ponds, lakes, and other still waters, so the 2016 individual probably was there only incidentally.

Twelve species were seen in the current survey that were not seen in previous surveys. Those additions most likely reflect the greater hours expended in the current survey rather than actual increases in odonate species diversity within the survey area.

Conservation Concerns and Recommendations

1. Habitat destruction and degradation from development probably pose the greatest short-term threats to odonates in the survey area. Acquiring (or otherwise protecting) the large undeveloped parcels in the Mount Moriah and New Hope Creek Bottomlands should be given high priority.
2. If land acquisition/protection is not an option, then monitoring new development on adjoining properties for silt dam failures and other construction and post-construction water quality impacts is recommended.
3. Continue to monitor odonate populations in the project area. This might be done informally by using signage to encourage photographers, birders and other visitors to take photographs and then submit them to an iNaturalist project page.

References

Hall, S.P. 1995. Inventory of the Wildlife Habitats, Movement Corridors, and Rare Animal Populations of Durham County, North Carolina. Unpubl. Report. NC Natural Heritage Program, Durham County Inventory Review Committee, Triangle Land Conservancy. Available online at: https://digital.ncdcr.gov/digital/collection/p16062coll9/id/331535

North Carolina Biodiversity Project, 2021. New Hope Creek Biodiversity Survey 2021 – 2022 https://auth1.dpr.ncparks.gov/ncbp_neho/index.php

LeGrand, H., T. Howard, J. Petranka, and M. Shields. 2022. *The Dragonflies and Damselflies of North Carolina. 12th Approximation* [Internet]. Raleigh (NC): North Carolina Biodiversity Project and North Carolina State Parks.
Available from https://auth1.dpr.ncparks.gov/odes/a/accounts.php.

Paulson, D., 2022. The Odonata of North America, Dragonfly Society of the Americas. https://www2.pugetsound.edu/academics/academic-resources/slater-museum/biodiversity-resources/dragonflies/north-american-odonata/

Paulson, D., Schorr, M., and Deliry, C., 2022. World Odonata List. https://www2.pugetsound.edu/academics/academic-resources/slater-museum/biodiversity-resources/dragonflies/world-odonata-list2/

Troast D, Suhling F, Jinguji H, Sahlén G, Ware J (2016) A Global Population Genetic Study of *Pantala flavescens*. PLoS ONE 11(3): e0148949. https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0148949&type=printable

Orthoptera

Biology and Characteristics

This group comprises grasshoppers, crickets, and katydids, all of which can be recognized by their elongated hind legs that are used for jumping. The males of many of these species are capable of producing songs, which they use similarly to birds and frogs, attracting mates and defending territories. As very active singers and jumpers, they are one of our most conspicuous groups of species, both day and night. They can also be extremely numerous. Grasshoppers and Meadow Katydids are some of our most abundant insects in grasslands and marshes. Other katydids are canopy dwellers in both hardwood and conifer forests. Still others are associated primarily with shrublands. Crickets, on the other hand, are highly diverse in the leaf layers of forests and shrublands, although there are also a number of arboreal species, some of which live up in forest canopies along with the tree katydids.

As abundant herbivores and omnivores, and more rarely predators, Orthopterans play major trophic roles in all terrestrial ecosystems. They are particularly important as the food for grassland and marshland birds and the decline of those species may be strongly associated with the decline of their prey base.

Survey Efforts

Acoustic surveys (see Riede, 1998), involving the use of a digital recorder and shotgun mic, were conducted in the fall of 2021, a peak time for singing species of Orthopterans. Ten or more species were recorded on each of the following dates: September 3, 21, 29, October 27, and November 9. At other times, singing insects were recorded using a digital voice recorder. In all of these cases, songs were analyzed using the RAVEN Lite program obtained from the Cornell Laboratory of Ornithology

Sight observations of grasshoppers and other diurnally active species were recorded opportunistically throughout the survey. Along with the song surveys, records for Orthoptera were made on 46 different dates during the inventory. Only one survey was conducted at night, however, with the result that a number of species of tree-crickets and katydids that sing only after dark were likely missed.

The song surveys were done mainly by Steve Hall, but John Petranka contributed some of these sound records and also submitted a number of records for grasshopper species. Tracy Feldman contributed the sole record for the Carolina Leaf-roller cricket.

Summary of the Orthopteran Species Recorded During the Project

A total of 45 species were observed during the survey, including 20 crickets, 9 katydids, 10 grasshoppers, 4 grouse locusts, 1 mole cricket, and 1 leaf-roller. See Appendix 8 for the complete list of species.

The number of Orthopterans recorded in the New Hope project area comprise only 38% of the 117 species that have been recorded in the Triangle Region overall (as documented for Orange, Durham, Wake, and Chatham Counties in the Orthoptera of North Carolina Website). Excluding species whose habitats are not well-represented within the project area, there are still 43 more species that could be expected to occur there. Twenty-eight of these species are active mainly at night and a few others – including the Eastern Ant Cricket – require specialized sampling methods; these are species that were missed due to our focus on general, diurnal search methods. That leaves 15 species that could be expected to have been found with a greater degree of effort using the survey methods that were actually employed.

Noteworthy Species

None of the Orthopteran species observed in the survey are considered to be of conservation concern by the Natural Heritage Program: none are state-ranked as S3 or higher. In general, the Orthopteran fauna has not been as thoroughly surveyed as other groups and this survey added 27 species to the Durham County list. One of those species, the Armored Pygmy Grasshopper (*Tettigidea armata*), was previously known in North Carolina only from a handful sites in the Coastal Plain.

Overall Quality of the Orthopteran Community

The previously discussed limitations of the survey aside, the overall composition of the Orthopteran fauna appears to be representative of the habitats that are present within the study area. Although we have no historic records for this group within the project area, we did not detect any systematic absences that would indicate any major impacts to this group of species. The 45 species found in this survey actually compare favorably to the 40 species recorded at Mason Farm, the site most similar to the New Hope study area in terms of geography, habitats, and survey efforts aimed at the Orthopteran community (see Orthoptera of North Carolina Website).

Conservation Concerns

Unlike the Macro-moths, which appear to have undergone a massive decline over the past thirty years (see Moths summary), the Orthoptera seem to have maintained at least the diversity of their species and possibly also their abundance of individuals; without surveys having been conducted previously, however, this cannot be known for certain. Unlike the moths, which contain a number of host-plant specialists, Orthopterans tend to be more generalized feeders. In the study area, only three pine-associated species are likely to be present (none of which were documented), whereas six species of macro-moths are highly specialized on Ash species. Due to that strong association, however, the Ash-feeding moths

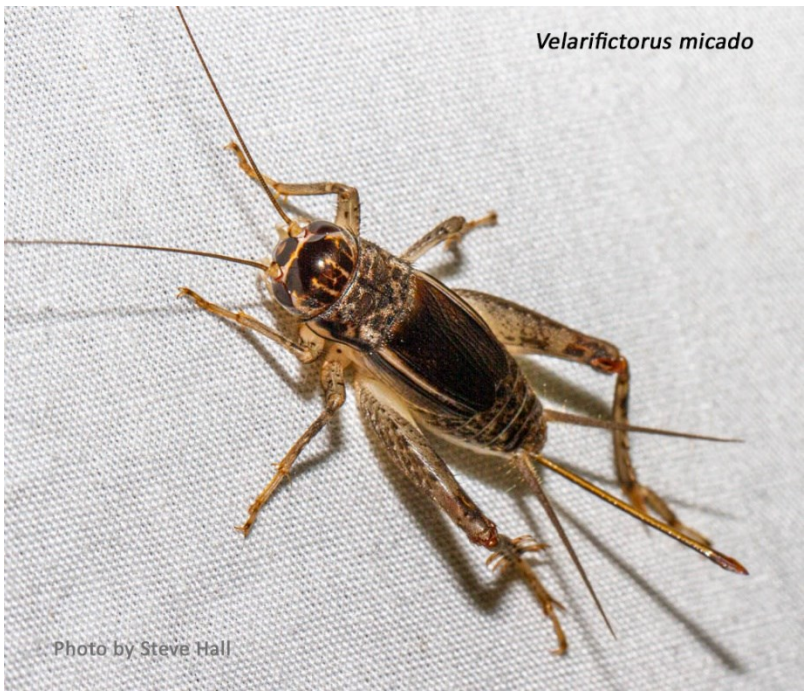
have nearly disappeared from the area as a result of the massive depredations of the Emerald Ash Borer. The katydids and crickets that may have regularly fed on Ash species, however, are still present due to their ability to make use of other tree species.

Orthopterans are also generally more sedentary than Lepidopterans: just within the species documented in the study area, one species – the Carolina Leaf Roller – has completely lost its wings and nine others are also flightless, having lost their hindwings (the forewings are retained for singing, but are also often highly reduced). Still others have both flightless and flying individuals present in their populations, and even species such as the True Katydid that have hindwings may not actually use them for flying. In comparison, none of the moths are completely flightless, although in a very few Geometrids, only the males have wings.

The lesser reliance on mobility in Orthopterans is an indication that their populations are rarely extirpated locally; they do not rely on recolonization from other areas to restore their populations as much as moths do. They are consequently less affected by habitat fragmentation, at least as it disrupts dispersal. As long as the habitat patches are large enough to support a population, Orthopterans can persist indefinitely, similar to many plant species but unlike Lepidopterans, which often require a metapopulation structure, involving a number of sub-populations linked by dispersive movement. Only where massive losses to their habitats have taken place have Orthopterans become reduced to tiny, relict populations – most Orthopterans that are considered to be of conservation concern fall in that category. However, none of those species are associated with the still broadly distributed bottomland forests and wetlands found in the study area.

Finally, the lower mobility requirements of Orthoptera may expose them to fewer of the impacts that are affecting moths and other dispersal-dependent insects. They may, for instance, be much less affected by light pollution – a major disruptor of nocturnally-flying insects – than moths and the other taxa that appear to be undergoing severe declines.

Other impacts to Orthoptera, however, may simply be escaping our notice. One exotic species, the Japanese Burrowing Cricket (*Velarifictorus micado*), is now found in virtually all terrestrial habitats in the state, from Mount Mitchell to the Tidewater region. It also now appears to be the most abundant cricket in many of those habitats, which is very likely having a significant impact to our native species. *Gryllus* species, which have similar feeding and general habitat requirements, may be particularly affected although they currently still seem to be doing well. Since this species does not seem to have become a “pest” with regard to any plants considered important for human uses (it does, however, occur in lawns), it receives little or no attention from either the general public or from conservationists.



References

Riede, K., 1998. Acoustic monitoring of Orthoptera and its potential for conservation. Journal of Insect Conservation, 2(3), pp.217-223

Hemipteran Hoppers

Biology and Characteristics

This group comprises members of the Hemipteran suborder Auchenorrhyncha, including the Leaf Hoppers, Tree Hoppers, Plant Hoppers, and Spittlebugs, all of which have strong hopping or jumping abilities (Cicadas also belong to this suborder but are incapable of jumping). All members of this group have similar forewings and hindwings ("homopterous") and are typically brightly colored. Many species, particularly the Tree Hoppers, are ornamented with spines, ridges, and other projections of their exoskeletons. All have piercing mouthparts and feed on plants, both woody and herbaceous species.

Survey Efforts

A total of 62 records were made on 23 dates, including 12 between July and December 2021, and 11 from March through August in 2021. Records were made at night on September 29, 2021, using sheet sampling and UV lighting; the rest were made through direct searching of foliage during the day. Most of the records were made by John Petranka, Brian Bockhahn, and Tracy Feldman. Records were vetted by Kyle Kittelberger.

Summary of the Hemipteran Hoppers Recorded During the Project

A survey of hemipteran hopper fauna revealed 26 species and an additional 10 groupings of hoppers that were not able to be identified to species level. All of the species were locally common to widespread species in the state, which one would expect to find when sampling in the Piedmont- some of these species represent some of the most abundant hopper species in North Carolina.

Noteworthy Species

The most noteworthy records pertained to two "unidentified groupings"- *Erasmoneura atra* or *nigra* and *Lavicephalus* unidentified species. The former is fairly uncommon in the state, recorded from only a handful of counties, and the two species can only be separated based on male genitalia or host plant. *Laevicephalus* is a very infrequently encountered genus in the state and typically requires a view of the external genitalia features to determine species

Butterflies

Biology and Characteristics

Butterflies are one of the thirty to forty super-families (depending on the source) included within the Order Lepidoptera, the vast majority of which are termed "moths." While we could do a combined summary for Lepidoptera as a whole, we have chosen, instead, to divide them into three quasi-taxonomic groups: Butterflies, Macro-moths, and Micro-moths. These groups are based partly on biological features and life history differences, but also on the methods used to survey them: butterflies can be surveyed by direct observation, similar to birds; many micro-moths can also be detected by direct observation, but based on the characteristic shelters constructed by larvae or by their feeding sign; macro-moths are usually sampled at night using either bait or ultraviolet lights to attract the adults.

As colorful, day-active, flower-visiting, and non-stinging species, butterflies are the most popular group of insects. Ecologically, butterflies play important roles as pollinators, as herbivores, and as prey for other animals. Their life-histories, involving the mysterious transformation from worm-like caterpillars into beautiful, flying adults has been the subject of literature for thousands of years and is well-known even to nursery-school children.

Butterfly populations are some of the most easily monitored of all animals due to the diurnal behavior and high visibility of the adults. Recent studies in Europe and some parts of the United States have documented drastic declines, prompting concerns about their possible extinction. One species in particular, the Monarch, stands out as a flagship for insect conservation due to its heroic, thousand-mile migrations and concerns about its noticeably shrinking numbers. Several species found in North Carolina, however, are even rarer, including the federally Endangered St. Francis' Satyr (*Neonympha mitchellii francisci*), which is found only in a portion of Fort Bragg. Several others are known only from just one or two small populations, including the recently described Crystal Skipper (*Atrytonopsis quniteri*), whose entire known range is located on Bogue Banks, Bear Island, and a few neighboring dredge spoil islands. Three other species, the Arogos Skipper, Loammi Skipper, and Regal Fritillary have completely vanished from the state within just the past few decades (although they still exist elsewhere). Altogether, the North Carolina Natural Heritage Program currently lists 39 butterfly species as Significantly Rare in North Carolina. Although Insects as a whole are not included in the State's Endangered and Threatened Wildlife Act – which would give them legally protected status similar to what is given even to land snails and crayfish – they are nonetheless highly important indicators of North Carolina's environmental quality.

Survey Efforts

Butterflies were recorded in portions of the study area in the early 1990s during the Durham County Wildlife Survey conducted by Steve Hall (1995). The Orange County portion of what is now the Hollow Rock Nature Park was also surveyed for butterflies by Hall in 2005 as part of a

site assessment used to support the conservation of this tract. Together, these two surveys provide a basis for comparison to current conditions, allowing the potential detection of changes that have taken place in the butterfly fauna specifically in the current study area over the past 30 years. Observations were made opportunistically during those two surveys, which included the documentation of several other groups of animals. Butterflies were recorded on seven different dates during these inventories, with a high number of twelve species recorded on two different occasions.

In the current survey, butterflies were similarly recorded on an opportunistic basis and throughout the year, with observations made in each month from March through November. Butterflies were observed on 53 different dates, with a high count of 10 species observed on one occasion. John Petranka contributed 54 of these records; Steve Hall contributed 39 (plus 28 from the earlier studies); and Harry LeGrand contributed 29. Other participants, including Tracy Feldman, contributed smaller numbers and we also added a few records from submissions by the public to iNaturalist.

Most of the sampling in the current survey was done in the New Hope Bottomlands, where 79 of the records were obtained. Forty records were also made in the Orange County section of Hollow Rock Nature Park, but just two were obtained in the dry, upland woodlands on the east side of Pickett Road. The Mud Creek Bottomlands were not surveyed for this group.

Summary of the Butterfly Species Recorded During the Project

A total of 37 species of Butterflies have been recorded in the project area, including 35 recorded in the current survey, 16 of which were not recorded in the previous surveys conducted in this area. These are listed in Appendix 10.

Noteworthy Species

None of the Butterfly species recorded in the study area are considered to be of conservation concern: none are state-ranked by the Natural Heritage Program as S3 or higher. Neither were any new species added to butterfly list for Durham County, reflecting the generally intensive survey efforts directed at Butterflies, especially by dedicated amateur Butterfliers across the state. The following three species are state-ranked as S4, indicating that they are uncommon but probably secure in the state.

MONARCH (*Danaus plexippus*)

This is one of the flagship species for insect conservation but is only a transient resident in this state. The first generation returning from the Mexican wintering grounds produces a brood in North Carolina but the progeny of that brood continues on the way north and the final generation of the year only passes through on its way south, not stopping to breed. In the current survey, a worn individual was seen in the New Hope Bottomlands powerline in April, representing the return of the overwintering generation. In some parts of the powerline,

Swamp Milkweeds are present and likely support the larvae of this particular generation of Monarchs. None were observed in the current survey, however.

APPALACHIAN BROWN (*Lethe appalachia*)

This is a true bottomland species, occurring under forest cover but with its larvae associated with the extensive swathes of sedges (*Carex* species) growing in the wetter areas. This species was common in the New Hope Bottomlands, with several broods produced per year.

TAWNY EMPEROR (*Asterocampa clyton*)

This is a species that is particularly associated with rich bottomland forests, where its host – Sugarberry (*Celtis laevigata*) occurs. As such, it is one of the better indicators of the habitat quality of the New Hope Bottomlands. Although still widespread, it is considered to be fairly scarce, particularly compared to its congener, the Hackberry Butterfly. Both species were observed during the New Hope Project but the Tawny Emperor was seen only twice (once in October, 2022 after the field work for this survey was formally completed).

ZEBRA SWALLOWTAIL (*Eurytides marcellus*)

The Zebra Swallowtail (*Eurytides marcellus*) is state-ranked as S5 but is included here as one of the hallmark species of the study area. The larvae of this species feed on Pawpaws (*Asimina* species) which gives them a strong association with rich, bottomland hardwoods. Adults were commonly seen throughout the study area, particularly during the spring.

Comparison to Previous Results

Only one species, Horace's Duskywing (*Erynnis horatius*), was recorded in the study area by Hall (1995) but not found in the current survey. Conversely, 16 species were recorded in this survey that were not observed in the previous surveys. None of these species represent recent arrivals to the area, however, and were most likely missed previously due to the fewer days that were spent in this area. By themselves, these data do not indicate any significant change has occurred in the butterfly fauna of the area.

Overall Quality of the Butterfly Community; Comparison to other Sites

The 37 species of Butterflies recorded in the New Hope project area comprise only 31% of the 119 species that have been recorded in the Triangle Region overall (as listed for Orange, Durham, Wake, and Chatham Counties in the Butterflies of North Carolina Website). A large number of those species are strays, such as Zebra Longwing, or represent habitats that are not present in the study area, such as the Palamedes Swallowtail. Others, however, appear to be missing that are more typical of this area.

A better comparison is to the butterflies that have been recorded just at the Mason Farm Biological Reserve. This site is located only four miles away from the New Hope project area. Like the New Hope Bottomlands, it is located in the flat terrain of the Triassic Basin and has a similarly large tract of mature bottomland hardwoods. These forests were, in fact, part of a nearly continuous complex until the bottomlands of the former New Hope River were cleared during the construction of Jordan Lake.

The butterfly fauna of Mason Farm, additionally, is one of the best surveyed in the area. A list of the butterflies observed in the Reserve was compiled by Hall in 1984 (included in the species lists compiled by Sather and Hall, 1988) and has recently been intensively surveyed in the Mason Farm Butterfly Project, done as a partnership between Joel Kingsolver's lab in the UNC Chapel Hill Biology Department and the NC Botanical Garden (see https://ncbutterflies.web.unc.edu/). The goals of this project specifically include looking for changes in diversity and abundance that indicate the effect of climate change or other alterations of the habitat. A total of 71[1] butterfly species have been recorded at Mason Farm between 1984 and 2018.

All 37 of the species recorded in the New Hope project have been observed at Mason Farm but 34 additional species are included on the Mason Farm list. Many of these species may have been missed simply because of differences in sampling intensity; far fewer sampling visits were made to the New Hope project area and usually not specifically to survey butterflies, as they were at Mason Farm. Nonetheless, there appear to be some patterns in the species that were missed related to habitat: most of these missing species appear to be associated with habitats

[1] We regard a record entered for Southern Pearly-eye as a mis-identification of a Northern Pearly-eye.

that are of only minor importance in the New Hope project area but are common at Mason Farm.

This is particularly the case for species associated with old field or ruderal habitats, which are extensive at Mason Farm due to its long history of agricultural uses, but are much more restricted in the New Hope project area. While a few common species belonging to these habitats were found at both sites, e.g., Eastern Tailed Blue (*Cupido comyntas*), Pearl Crescent (*Phyciodes tharos*), and Fiery Skipper (*Hylephila phyleus*), eighteen species associated with early successional habitats were recorded at Mason Farm but not in the project area. These include such common old-field species as Gray Hairstreak (*Strymon melinus*), Sleepy Orange (*Abaeis nicippe*), and Sachem (*Atalopedes campestris*).

While some of the butterflies associated with this habitat could be expected to occur in the powerline right-of-way that runs through a large section of the study area, that strip is flooded on an increasing basis and is also sprayed with herbicides to keep woody vegetation from growing up under the powerlines. A treatment that was done in the summer of 2021 left very few flowers for butterflies or other pollinators and probably affected the diversity of caterpillar host plants as well.

In addition to old-field species, butterflies associated with marshes and pond edges also seem more poorly represented in the New Hope project area than at Mason Farm. As was the case with the old-field habitats, Mason Farm has a much larger expanse of open ponds and marshes, reflecting a long history of beaver activity at that site: extensive beaver-pond complexes have been present there since the late 1970s (Hall, pers. obs.). These marshlands, moreover, are not treated with herbicides as is the case with the powerline corridor in the New Hope Bottomlands, which contains the majority of marsh vegetation in the project area. Not seen at all in the project area were Least Skipper (*Ancyloxypha numitor*) – a very ubiquitous wetland species -- Northern Broken-dash (*Polites egeremet*), Southern Broken-dash (*Polites otho*), and Dion Skipper (*Euphyes dion*), and only a single individual was observed of Dun Skipper (*Euyphyes vestris*).

Upland forests are also scarce in the project area but well-represented at Mason Farm on an extensive slope bordering the west side of the Triassic Basin. Two species, Sleepy Duskywing (*Erynnis brizo*) and Banded Hairstreak (*Satyrium calanus*), have been long-present at Mason Farm but were not observed in the current project. That may, however, just reflect the fact that only a few visits were made to the eastern section of Hollow Rock Nature Park, which does, in fact, have a fairly large block of mature, dry-xeric hardwood forest.

Of greatest interest are the sixteen species that occur in the Triangle Region that are associated with general hardwood forests and particularly the wet hardwood forests that are the dominant habitat in the New Hope project area (see species lists given in the Habitat Analysis section). All but two of these species – Giant Swallowtail (*Heraclides cresphontes*) and Yehl Skipper (*Poanes yehl*) -- have been recorded at Mason Farm but four additional species were

missed in the New Hope survey: Pepper and Salt Skipper (*Amblyscirtes hegon*), Harvester (*Feniseca tarquinius*), Pipevine Swallowtail (*Battus philenor*), and Northern Pearly-eye (*Lethe anthedon*). The first two of these species are actually rare at Mason Farm and have not been recorded there since the 1980s; in the case of the Pepper and Salt Skipper, no records appear to have been made since 2011 in the entire eastern Piedmont (Butterflies of North Carolina Website). The last two species, however continue to be seen on a regular basis both at Mason Farm and throughout the region.

In addition to possible changes in species composition, the numbers of individual butterflies observed during the course of the project appeared to be much lower than we expected based on past butterfly surveys. Looking just at the forest species recorded during the two years of the current survey, the single record for Spicebush Swallowtail, the two for Red-spotted Purple and Question Mark, and the three for Tiger Swallowtail all seem remarkably low. Normally, we would expect to see all of these species throughout the growing season. Other species, however, still seemed plentiful, particularly Zebra Swallowtail and Appalachian Brown.

Conservation Concerns

Declines in butterfly diversity and abundance have been reported world-wide, as has been well-documented in long-term censuses conducted in several areas, including Britain (Fox et al., 2011), California (Forister et al., 2019), and Ohio (Wepprich, 2019). These declines have been especially severe in species, such as the Monarch and Checkered White (*Pontia protodice*), that are associated with open, herb-dominated habitats, particularly in areas located adjacent to agricultural lands, such as old-fields and pastures. At such sites, agricultural intensification – including the increased use of pesticides and fertilizers – has been implicated (see Goulson, 2021 for an extensive review). Within our study area, the absence of several species of old-field butterflies, along with smaller numbers of those that are still present, seems consistent with these trends, with the application of herbicides to maintain the powerline corridor a possible factor.

The same factors may also be responsible for the low diversity of marshland species recorded in the study area. Although many wetland insects have actually increased due both to improvements in water quality and the return of beavers to the landscape, open marshes in our study area were all located within the powerline corridor, where herbicide application is very likely limiting the growth of cattails and other marshland plants needed by the butterflies.

While forested habitats appear to show fewer missing species than the open habitats, even there the numbers of individuals of several species were much lower than observed in previous surveys. Populations of woodland moths are strongly declining (see Macro-Moth summary), and parallel declines in woodland butterflies should be expected.

Conservation Recommendations

1. Replace the use of herbicides within the powerline corridor with mechanical methods of suppressing woody vegetation. This is especially needed in the areas of incipient marsh development.
2. Monitor trends in butterfly diversity and abundance using quantitative survey methods (e.g., see Pellet et al., 2012).

References

Forister, M.L., Pelton, E.M. and Black, S.H., 2019. Declines in insect abundance and diversity: We know enough to act now. Conservation Science and Practice, 1(8), p.e80.

Fox, R., Warren, M.S., Brereton, T.M., Roy, D.B. and Robinson, A., 2011. A new Red List of British butterflies. Insect Conservation and Diversity, 4(3), pp.159-172.

Goulson, D. 2021. Silent Earth. Averting the Insect Apocalypse. HarperCollins, NY.

Hall, S.P. 1995. Inventory of the Wildlife Habitats, Movement Corridors, and Rare Animal Populations of Durham County, North Carolina. Unpubl. Report. NC Natural Heritage Program, Durham County Inventory Review Committee, Triangle Land Conservancy.

Pellet, J., Bried, J.T., Parietti, D., Gander, A., Heer, P.O., Cherix, D. and Arlettaz, R., 2012. Monitoring butterfly abundance: beyond Pollard walks.

Macro-moths

Biology and Characteristics

The Order Lepidoptera is one of the most diverse groups of all organisms, possibly second only behind beetles in its number of species. By far the majority of the species in this group are termed “moths,” with only about ten percent termed “butterflies,” the primarily diurnal and better-known group of this order. We further divide the moths into two quasi-taxonomic groups, the “macro-moths,” which include a group of six super-families that generally have much larger individuals and possess more advanced features than the “micro-moths;” all are considered to be fairly closely related to one another, forming a monophyletic group. Until recently, the macro-moths received far greater attention in both the taxonomic literature and field guides, owing primarily to their greater conspicuousness and long interest by collectors. Most moth surveys have concentrated on this group both for these reasons and the greater ease in specimen preparation of larger species.

Lepidoptera in general comprise the most important group of herbivores on the planet. That places them near the base of the food-web, just one step up from the primary producers. As such, they are the major prey base for secondary consumers, i.e., predatory species, which range from fungi, to other arthropods, and to a great many vertebrate species. Macro-moths, with their larger caterpillars, are particularly important food items for birds, and the adult moths for bats.

Moths in general include a large number of host plant specialists, probably more than any other group of herbivores. This reflects the long history of co-evolution between the moth species and their plant hosts. These relationships are very stable and this stability within such an important set of ecological relationships may be responsible in large part for the stability of ecosystem themselves.

The strong dependence of many moths on particular species or genera of plants, however, makes them particularly vulnerable to impacts affecting those species. The ten species of macro-moths in North Carolina that are strongly associated with Ash species, for example, are now suffering declines due to the impacts of the Emerald Ash Borer on their host plants. This vulnerability, on the other hand, makes these species excellent indicators of environmental quality – the more such specialists that occur at a site, relative to the expected number, the higher the estimate of habitat quality, i.e., how well the site matches the complete set of expected species.

Survey Efforts

No prior surveys have been conducted for moths within the project area. In the current survey, moths – both macro and micro -- were sampled using 15-watt UV bucket traps, making use of the disorienting effects of lights on night-flying insects. Bait painted on trees was used on one

occasion, coupled with sheet-sampling, which also uses UV lights. Both of these methods require direct observation of the species coming to these attractants, whereas the traps are left out over night with the specimens retrieved on the following day. The main advantage of trapping is that it allows the counting of individual moths that were captured during the entire night. The quantitative data that this method provides proves its worth in the analysis conducted below.

Trapping was done at approximately monthly intervals, with dates chosen close to the new moon – when attraction to lights tends to be greatest – but with weather factors also taken into consideration; warm nights with no precipitation but with some cloud cover were preferred. Sampling was done during the growing season, including one sampling date in November in 2021 and in March, May, June (2 dates), and August in 2022. All trap samples were done by Steve Hall.

Two traps were set out during each sampling period. Sampling sites varied between months, but one trap was usually located on an ecotone between bottomland forest and either an open marsh or a floodplain pool. The other was located deeper within the forest, typically where Big Shellbark Hickories were found. The aim was to maximize the diversity of the samples but to weight them toward the dominant habitat present in the site.

Summary of the Macro-Moth Species Recorded During the Project

161 species of macro-moths were recorded in the survey, representing eight families. Eleven were recorded at Hollow Rock Nature Park and two at the Mt. Moriah Bottomlands, all based on direct observation of larvae or adults. 136 species were recorded at the New Hope Bottomlands using light traps; ten using sheet sampling; five using bait; four from daytime observations of adults; and twelve based on observations of larvae or cocoons. A list of these species is given in Table 1.

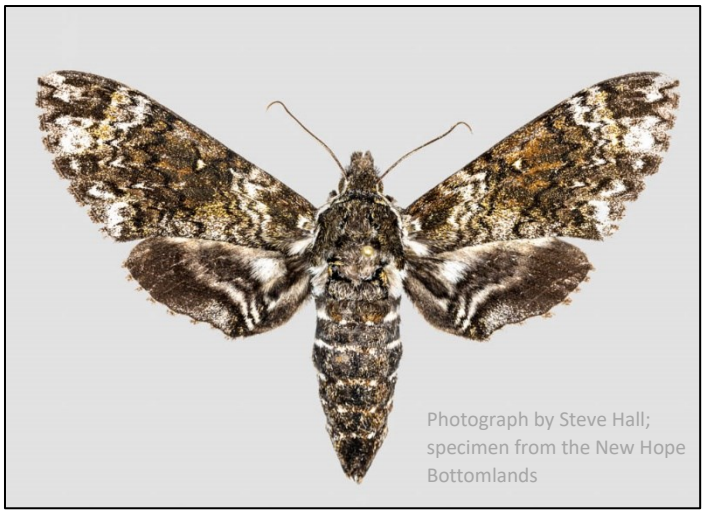
Noteworthy Species

S2S4 SPECIES

Inconsolable Underwing (*Catocala insolabilis*). This is primarily a Midwestern species whose larvae feed on species of Hickory. While Shellbark Hickory seems likely to be one of its hosts in the study area, it is known to use Pignut Hickory and possibly Bitternut Hickory elsewhere. Pignut, however, is primarily an upland species but Bitternut is common in the bottomlands

S4S5 SPECIES

Pawpaw Sphinx (*Dolba hyloeus*). This is the nocturnal counterpart to the Zebra Swallowtail. The larvae of both feed on Pawpaw, one of the hallmark plants of the study area.



Photograph by Steve Hall; specimen from the New Hope Bottomlands

Overall Quality of the Macro-Moth Community and Comparison to Other Sites

The lack of previous moth surveys in the New Hope project area precludes direct determination as to whether there have been any major changes in the fauna over time. However, there are a number of moth surveys that the Natural Heritage Program conducted in similar floodplain habitats from 1992 to 2013. These surveys followed the same methodology used in the current survey (and, in fact, made use of the same set of light traps). To some extent then, these samples can serve as surrogates for previous same-sites surveys although they differ not only in the time periods in which they were conducted but also in the detailed features of their habitats.

The seven sites selected for comparison to the New Hope Bottomlands are all located within the floodplains of brownwater rivers or streams. These are systems possessing sediments weathered from rocks in the Piedmont and/or Blue Ridge Mountains and are consequently relatively rich in minerals and high in pH. The forests associated with these floodplains are all similar in composition, with the stands at the nearby Mason Farm Biological Reserve and the two Piedmont sites along the Tar River being particularly close to the New Hope Bottomlands. The sites located along the Coastal Plain section of the Roanoke River differed more greatly, due to their possession of large tracts of cypress-gum swamp forests (the Tar River sites also possessed small tracts of Bald Cypress). In the following analysis, species that are associated exclusively with cypress swamps are excluded, as are other species confined to the Coastal Plain.

Figure 1a plots the number of individuals and Figure 1b the number of species collected per trap for each sampling date, expressed as the day of the year. For some sites, samples were taken in more than one year and in those cases, the lines connecting the different samples for a given site do not represent a continuous time series. In general, we believe that seasonal factors, particularly with respect to temperature and precipitation, outweigh any serial correlation that might exist between successive samples taken at a given site.

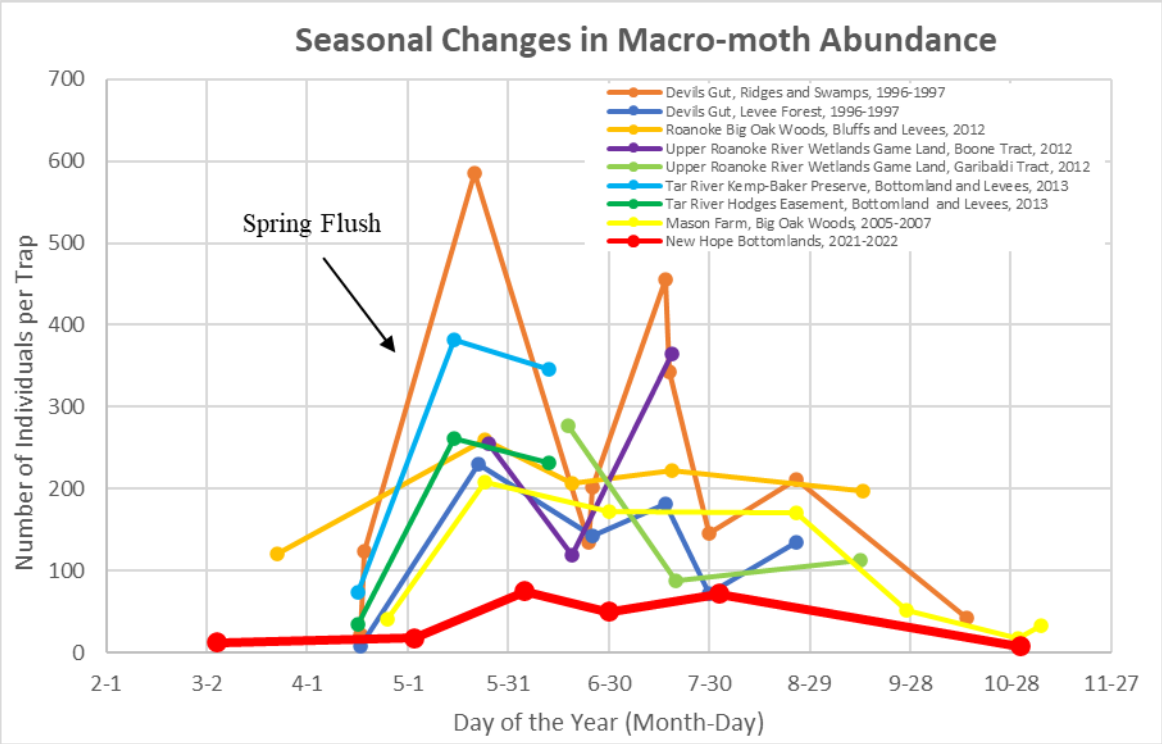


Figure 2a

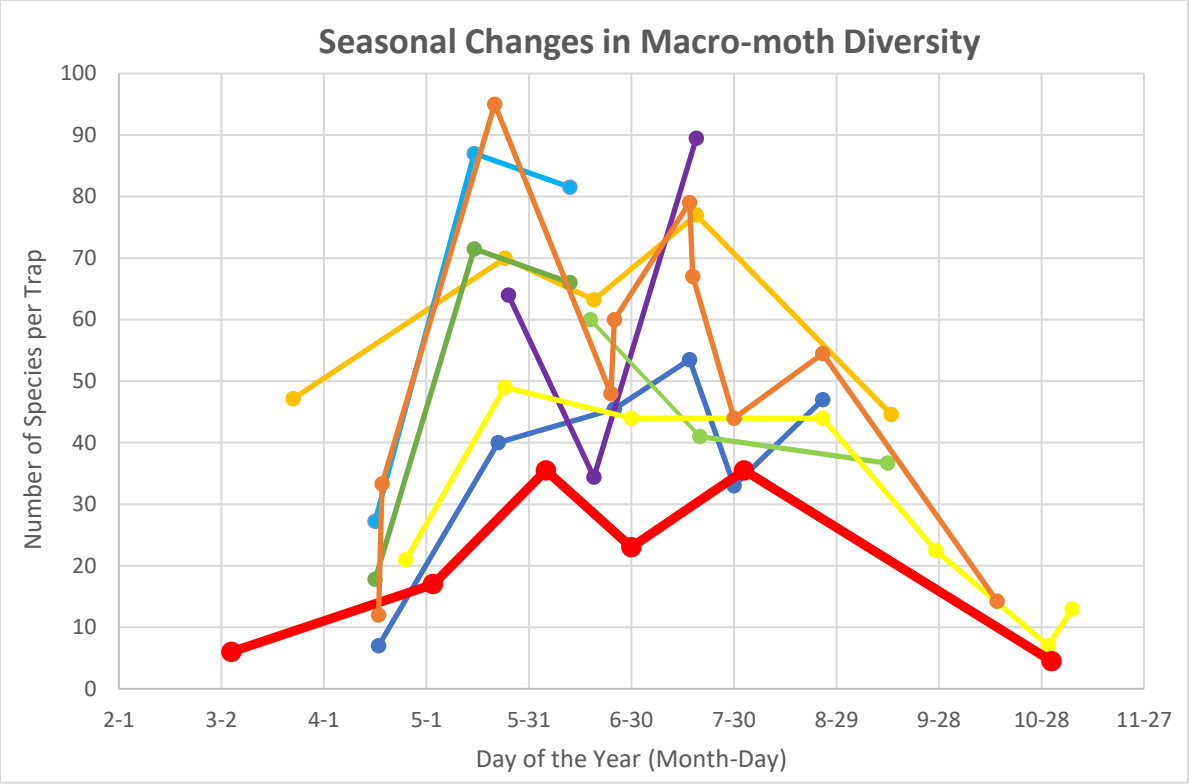


Figure 1b

Both graphs show a similar bimodal phenological pattern. A low level of adult activity exists during the winter, with only a few species flying during that season. This lasts until the early spring when there is a massive burst of larval activity, which in many species is timed to correspond with the emergence of new foliage. This spike in larval numbers – of extreme importance to Neotropical migrant birds that time their arrival on their nesting grounds to correspond to the spring flush in caterpillars -- is followed a few weeks later by a peak in the number of adult moths, typically in May. In these bottomland forests, at least, this is the peak period for both abundance and diversity of macro-moths and is followed by a period of low adult activity where caterpillars are in the process of developing. A second peak in adult moths then occurs, which is typically lower than the spring peak. A third, still lower peak occurs around the end of August and then numbers decline down to the winter lows.

The pattern shown by the New Hope samples (thick red line) generally follows the same pattern as the other sites, although their dates are somewhat offset to the right of the graph, probably due to differences in the moon phases from the other years included in this set of samples. Even taking those discrepancies into account, the samples of macro-moths taken in the New Hope study site are conspicuously lower in both abundance and diversity than observed at any of the other sites. These differences are also evident in several ecological and taxonomic subgroups, which we next examine to see if there is any pattern that can help explain these findings (see Table 2 for a list of the species included in each of these groups).

LITTER-DWELLING MOTHS. The Herminiinae, a subfamily of the Erebidae, and the Slowpoke (*Athetis tarda*), a member of the Noctuidae, feed primarily on decaying leaf litter and other detritus (a few also feed on living or withered vegetation in the herb layer). These species are found in forests across the state and are typically abundant in hardwood habitats, both upland as well as bottomland. Forty-nine of these species occur in the samples analyzed.

Figure 2 shows similar, but more condensed comparisons for this ecological group as previously shown for the entire set of macro-moths. In this case, the numbers of individuals and species collected per trap in the New Hope Bottomlands are compared to the combined samples for the other eight sites; the data here are also pooled per month (note that no samples were taken in the New Hope Bottomlands in the months of April, July, September, and November; in other months empty spaces represent zero specimens collected for this particular group).

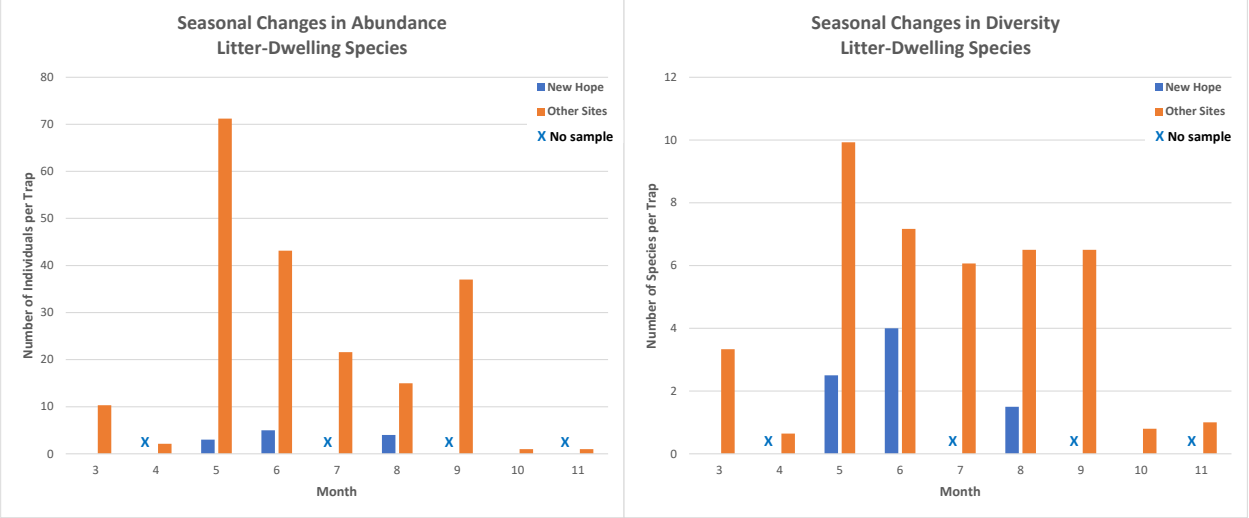


Figure 2

As was true for the macro-moths as a whole, there is a spike in adult abundance and diversity that occurs in May. However, in this case, the timing is not tied to the emergence of new foliage, at least as a food resource. Instead, larvae typically overwinter (Wagner et al., 2011) and mature rapidly once the ground layer warms up in the spring, producing this initial flush in abundance. Numbers remain fairly high throughout the summer and then rapidly decline in the fall.

The number of species and particularly the number of individuals are again strongly reduced in the New Hope samples compared to the other floodplains. A couple of species particularly stand out in terms of their abundances. Based on the months where samples exist for both the New Hope Bottomlands and the other sites, the Rotund Idia Moth (*Idia rotundalis*) -- one of the most common and ubiquitous species across the state – had only 1.25 individuals per trap, with a maximum value of 2 for the New Hope samples, whereas the value for the other sites was 8 per trap and a maximum of 39. Similarly, for the Slowpoke Moth (*Athetis tarda*), the average for the New Hope Bottomlands was 1 individual per trap and a maximum of 1, compared to 11 per trap and a maximum of 69 in the other floodplains.

This group of primarily litter-dwelling species seems particularly vulnerable to flooding in all of their life stages except possibly the adults. If the frequency, duration, or extent of flooding that now occurs in the New Hope floodplain is significantly more severe than it was in the past for the other floodplains included in this comparison, the observed differences in abundance and diversity could be easily explained by this fact alone. Extreme flood events are, in fact increasing in this area (see graph provided by the Durham County Office of Sustainability; see references given below) and major floods in the New Hope drainage recently occurred in the summer and fall of 2020.

BARK-DWELLING MOTHS. Several moths have diets similar to the Litter-Dwelling group, feeding on fungi, lichens, mosses, bark algae and organic detritus, but dwelling up on tree trunks rather than in the ground litter. These include the Lichen Moths, members of the Tribe Lithosiini of the Erebid subfamily Arctiinae, and the Fungus Moths, members of the Erebid subfamily Boletobiinae. Other species included in this group are the Erebids *Schrankia macula*, *Sigela brauneata*, and *Nigetia formosalis*; the Noctuids *Chytonix palliatricula*, *Elaphria versicolor*, *Elaphria georgei*, and *Elaphria grata*. One Geometrid is also included, *Glenoides texanaria*. Like the Litter Moths, members of this group occur widely across the state and are often among the most abundant moths collected in light traps. A total of 22 species occurs within the area covered by the floodplain samples analyzed here.

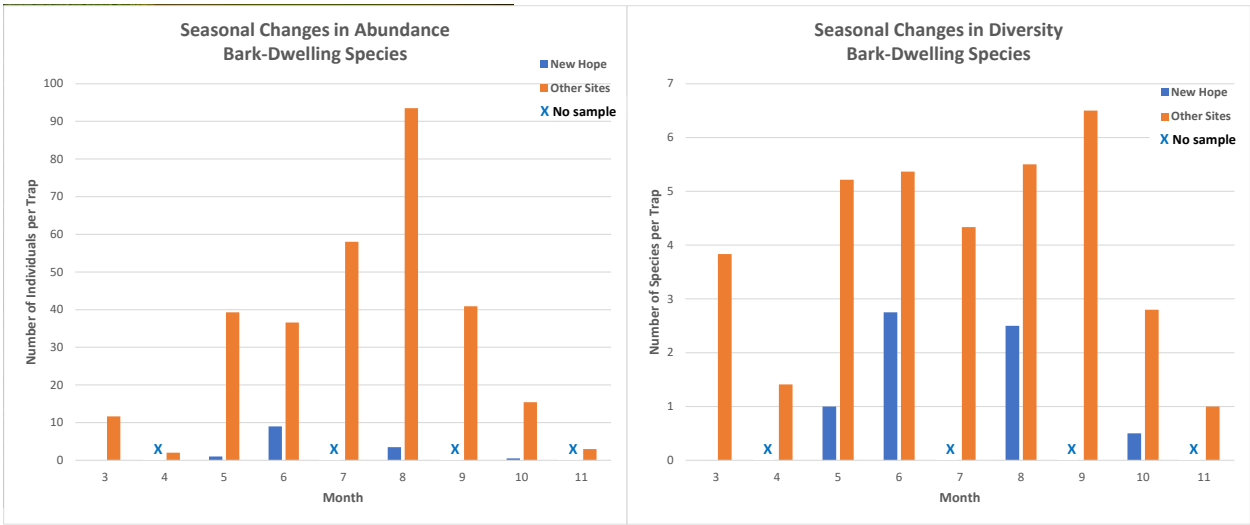


Figure 3

The bark-dwelling habit of these species would seem to make them somewhat less vulnerable to flooding than the Litter Moths, particularly species such as the Little White Fungus Moth (*Clemensia albata*) that pupate up on the bark (McCabe, 1981). Nonetheless, this group shows a similar paucity in the diversity and particularly the abundance in the New Hope samples compared to those of the other brownwater river floodplains.

Again, these differences are especially pronounced in several individual species. For the Painted Lichen Moth (*Hypoprepia fucosa*), an average of only 4 individuals was captured in the New Hope Bottomlands, with a maximum of 6 in one trap, versus an average of 23 and a maximum of 131 for the other floodplains. For the Little White Lichen Moth, the average for the New Hope Bottomlands was 1.25, with a maximum number of 2, compared to an average of 8 for the other sites and a maximum value of 39.

The arboreal life histories of this group should reduce their exposure to flooding. Moreover, the increased humidity that accompanies more frequent flooding may even increase the growth of the bark algae that some of these species depend upon. *Clemensia albata*, for instance, seems to prefer trees closer to streams possibly for that reason (McCabe, 1981).

WETLAND HERB-FEEDING SPECIES. Macro-moths that feed either on sedges and other wetland graminoids (e.g., the Spotted Grass Moth, *Rivula propinqua*) or on broad-leafed forbs associated with mires and shorelines are characteristic members of floodplain habitats and are likely to be adapted to some extent to flood events. Such adaptations could include toleration of submergence for at least short periods of time or selection of pupation sites that are out of

reach of normal flood heights. If it is mainly flood frequency that has changed but not depth or duration of flooding, then there might be little difference between the New Hope Bottomlands and the other floodplains, even if some change in flooding has taken place.

As shown in Figure 4, however, the pattern is still much the same although the data for August shows a reversal in both abundance and diversity compared to the data previously presented, the only such departure found in our analysis (but note the very small number of species and individuals involved in these samples, an average of less than five individuals and four species per trap).

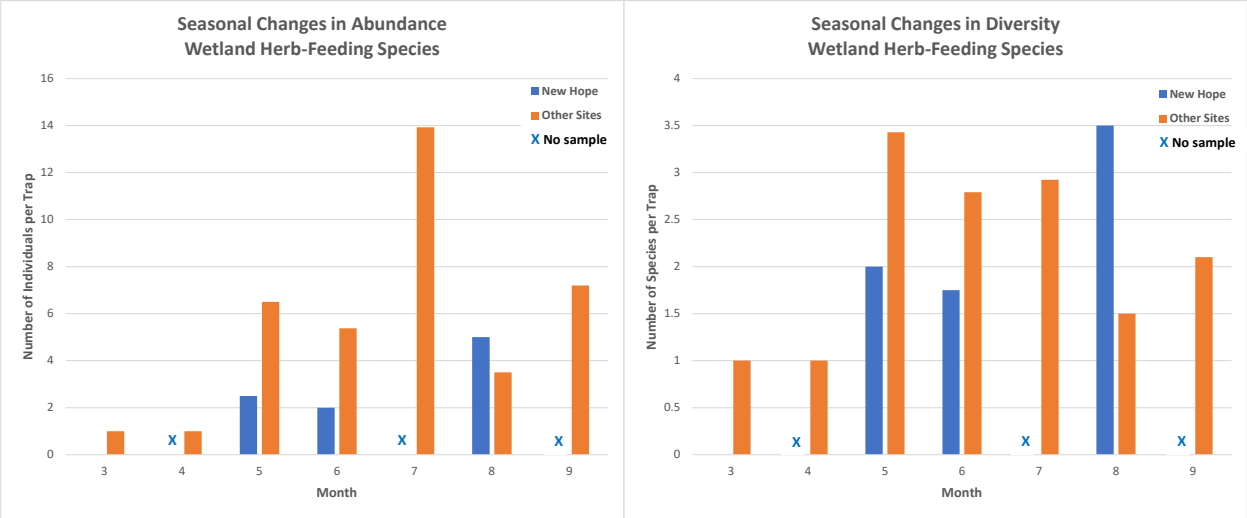


Figure 4

BOTTOMLAND HARDWOOD-FEEDING SPECIES. A larger group of moths that are associated mainly with floodplains are the species that specialize on the hardwood trees, shrubs, and vines that are characteristic of bottomlands. As in the preceding group, these species are at least somewhat adapted to frequent floods; in this case, the heights above the ground that their caterpillars occupy in feeding and sheltering give them a great deal of protection.

Nonetheless, as shown in Figure 5, the samples for the New Hope Bottomlands shows the same large deficit in abundance and diversity as in the groups described above. Several characteristic bottomland species were completely missing, including the Drab Prominent (*Misogada unicolor*), a species that feeds on Sycamore, and the Birch Dagger (*Acronicta betulae*), a species that feeds on River Birch. In comparison, Drab Prominent was found at six of those sites the Birch Dagger was found at four.

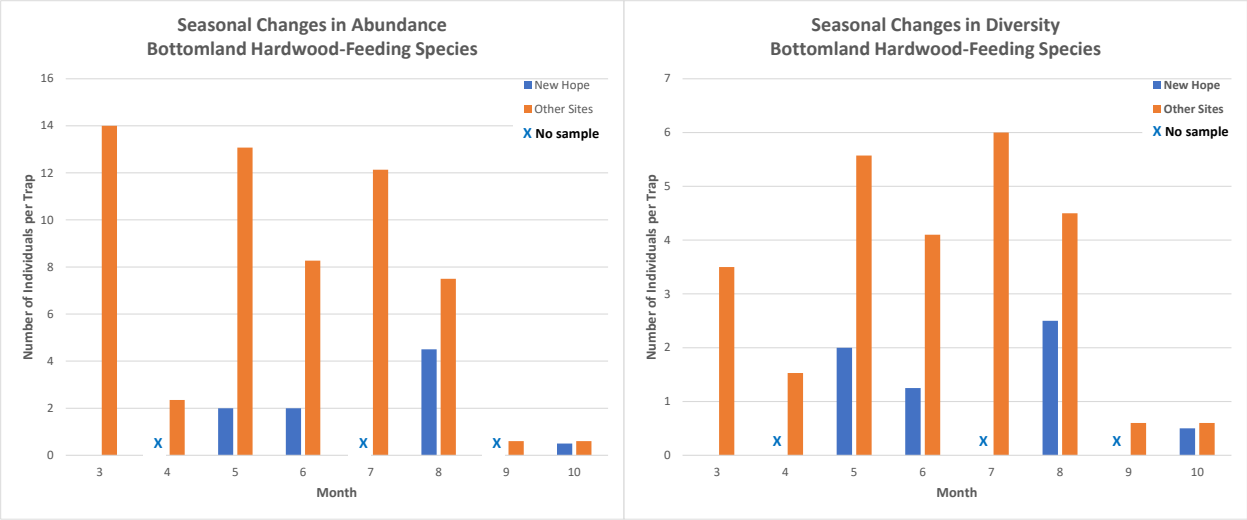


Figure 5

These findings do not completely rule out flooding as an impact, however: nearly all of the members of this group pupate or overwinter as larvae in the soil or leaf litter. A dramatic increase in the severity of winter flooding in the New Hope Bottomlands, relative to the past levels in the other floodplains, could explain this difference.

GENERAL HARDWOOD-FEEDING SPECIES. In addition to the macro-moths that specialize on the trees and shrubs that are characteristic of bottomlands, there is a large group of hardwood tree- and shrub-feeding generalists that occur in both upland and bottomland habitats (e.g., species that feed generally on oaks). As such, they are unlikely to have any special adaptations with regard to flooding.

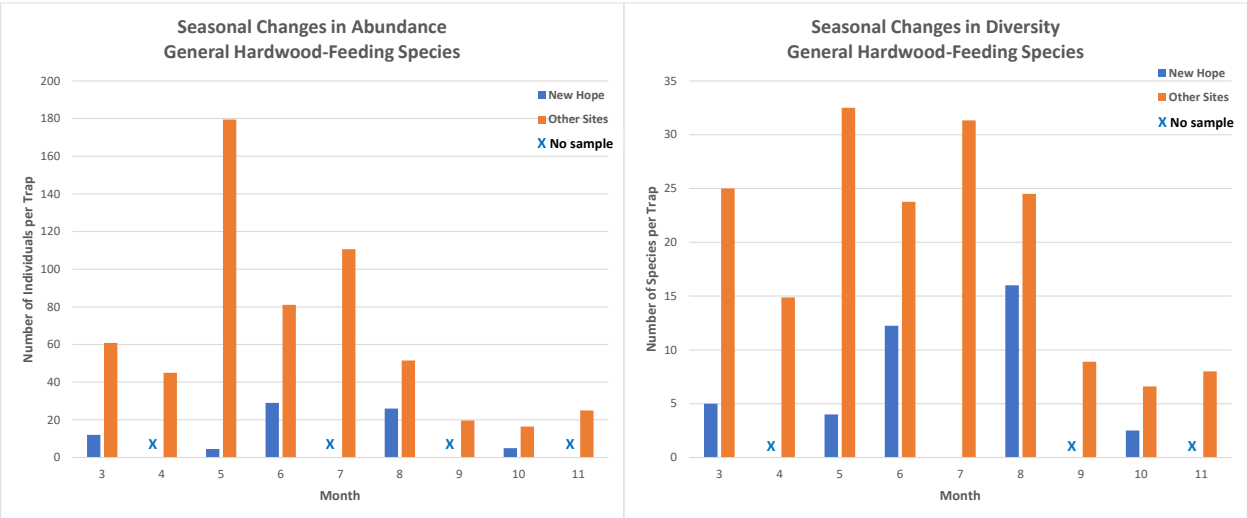
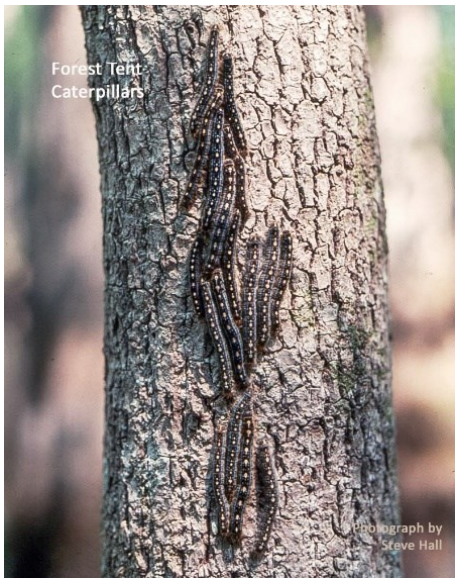


Figure 6

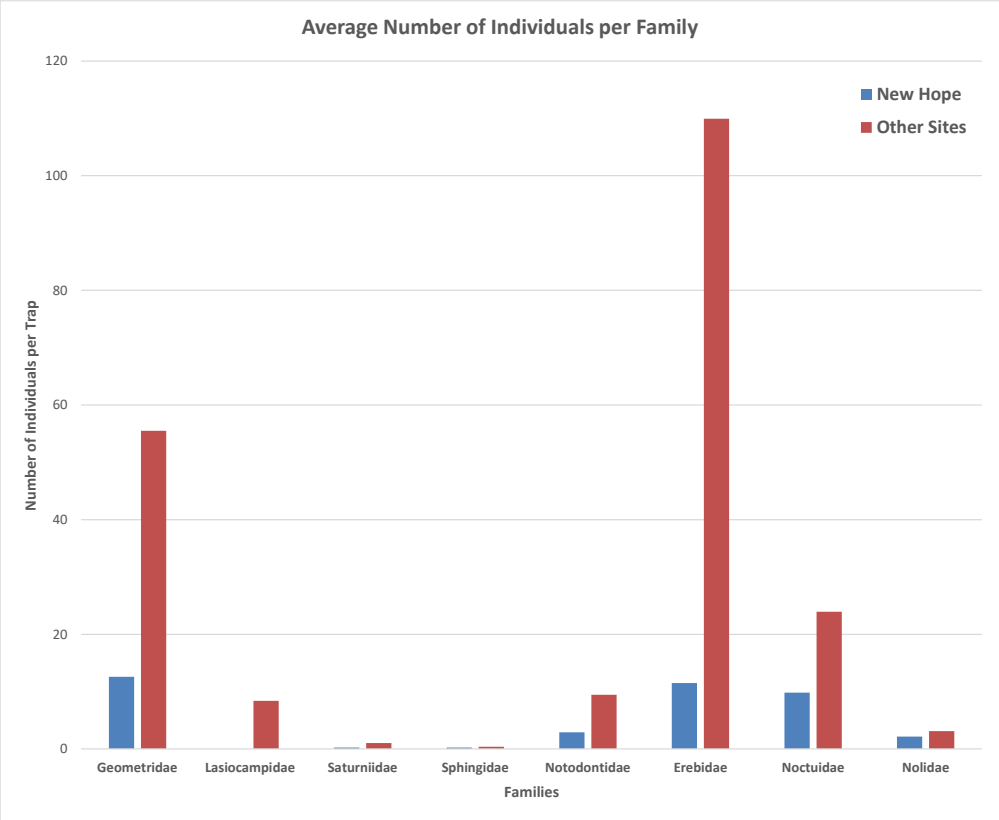
The pattern of differences between the New Hope Bottomlands and the other floodplains is again similar to that shown in the previous groups. The May samples – the peak of macro-moth abundance and diversity at all of these sites – show a particularly large difference. Among the nine species that averaged over 10 individuals per trap in that month for the non-New Hope sites, the two species of Tent Caterpillars particularly stand out. The Eastern Tent Caterpillar (*Malacosoma americana*) had an average of 22 individuals per trap and the Forest Tent Caterpillar (*Malacosoma disstria*) averaged 11 per trap. Neither, however, was collected at all in the New Hope Bottomland during this survey.



The two Tent Caterpillar moths exemplify the generalized nature of the habitats used by this group of species: both occur across the entire state, occupying virtually all habitats that possess populations of hardwood trees or shrubs, including upland as well as bottomland examples. Both have one key adaptation that helps them make use of even hydric habitats –they pupate up in trees or other sites off the ground (Wagner, 2005). Without any other obvious specialization, the Forest Tent Caterpillar in particular is a major herbivore in swamp forests. In the Lower Roanoke Floodplain, this species is capable of defoliating thousands of acres of Water Tupelo in the early spring, when water levels are quite high throughout the floodplain (Hall, 1996). The apparent absence of this species from the New Hope Bottomlands, therefore, is a strong indication that flooding at that site is not responsible for the extremely low number of at least this group of macro-moths.

One other subgroup of hardwood generalists needs special mention: species that are strongly associated with Ash species were a particular target of this survey due to the massive destruction of Green Ash (*Fraxinus pennsylvanicus*) in the New Hope Bottomlands by the introduced Emerald Ash Borer (see Wagner and Todd, 2016, for a complete list of the affected species). This group includes eleven macro-moths in North Carolina, six of which occur in the eastern Piedmont and Coastal Plain. Given the level of destruction that has occurred within just the past five years, we were uncertain whether any of these species have survived. None, in fact, were recorded in the New Hope Bottomlands but given the extremely low number of macro-moths in general, it is now difficult to determine how much of this decline is due specifically to the impacts of the borer.

TAXONOMIC COMPARISONS. The comparisons described above all involve ecologically-defined groups. The same pattern, however, also cuts across the entire range of taxa included within the macro-moths. Figure 7 shows the total number of individuals collected in the more abundant or better-known families, divided by the total number of samples (only months



where samples were made in the New Hope Bottomlands and the other floodplains are included in this analysis).

As was true for the ecologically-defined groups, the average number of individuals for the New Hope Bottomlands was consistently smaller than the corresponding value for the other floodplains, across the entire range of macro-moth families (including those not shown).

Conservation Concerns

Comparing data involving large numbers of species and samples taken from different sites, seasons, years, and local environmental conditions is a difficult problem in itself, let alone when using information from surveys that were not done with this sort of comparison in mind. While the techniques of meta-analysis could probably be used to draw some conclusions about at least the significance of the differences we have detected, we rely instead on the overall consistency of the patterns we have just described: the numbers of species and individuals per sample have been smaller in all but one case in the New Hope samples compared to those from the other sites. Based on this consistency alone, we believe that the macro-moth fauna of the New Hope Bottomlands is significantly depauperate compared to other brownwater floodplains in the region.

Without any previous samples taken from the New Hope Bottomlands themselves, however, we are unable to say how long these conditions have existed. Even so, these findings appear to

be highly consistent with those of other studies that have documented recent, massive declines in insect faunas – including macro-moths in particular – from various sites around the entire planet (e.g., see Fox, 2013; Hallmann et al., 2017; Lister and Garcia, 2018; Sánchez-Bayo and Wyckhuys, 2019; Goulson, 2021; Wagner et al., 2021; Blumgart et al., 2022). Although these declines have probably been taking place over a long period of time, the pace seems to be accelerating and the realization of just how large and widespread these losses have been is shocking. That certainly has been true in our case, coming face-to-face with a global catastrophe at a very local level. We had no prior expectations of uncovering this situation and, in fact, without the serendipitous existence of previous quantitative surveys of macro-moths taken in similar habitats, we would not have been able to say anything about the precarious status of this particular faunal group in this particular floodplain.

Determining the causes of these declines, as well as proposing conservation counter-measures has proven very difficult (see the extensive discussions by Goulson, 2021 and Wagner et al., 2021). The study by Hallmann et al. (2017) was particularly startling in that the declines in insect populations were documented within areas that had been specifically set aside as nature preserves, paralleling the situation that we have discovered in the New Hope Bottomlands. In Germany, where Hallmann et al. conducted their surveys, the nature preserves were embedded in vast agricultural lands and either the spill-over of agricultural chemicals into the natural areas, or their impact on insects dispersing across those areas were possible explanations. That does not seem to be the likely cause in the New Hope watershed, however, which generally lacks large areas of cultivated land. This is especially true with regard to our particular study area. If anything, the other sites included in the comparisons are much more closely adjoined by large tracts of agricultural lands, particularly those along the lower Roanoke floodplain.

Hallmann et al. were particularly looking for effects due to climate change but could not find any evidence that they were responsible for the declines they observed. In our area, we have also not yet experienced the sort of droughts, prolonged heat waves, or increase in wildfires that could explain the declines in the macro-moth fauna. While there has been a steady increase in the amount of flooding that has occurred in the New Hope floodplain, that appears to explain, at best, just a part of the decline, especially for the species associated with the litter or herb layers of the forest. As discussed in the preceding sections, however, flooding by itself does not seem adequate to explain all of the losses that have apparently occurred.

The most obvious difference that sets the New Hope Bottomlands apart from the other floodplains included in our comparisons is its closeness to urban development. The floodplains along the Roanoke and Tar Rivers are located in sparsely populated parts of the state and even the Mason Farm Reserve in Chapel Hill is fairly remote from any areas of extensive development. In contrast, the lands adjoining the New Hope Bottomlands have become increasingly developed over the past thirty years, with high density developments now located along both sides of the floodplain.

For insects in particular, there are several factors related to urban proximity that are believed to have potentially strong impacts on their survival:

- Artificial lighting. The flights of nocturnal insects, including macro-moths, have long been known to be disrupted by artificial lights, causing disorientation that often traps the species in the vicinity of the lights, where predation by bats, birds, and other species can take a heavy toll. Large urban areas that are well-lit at night may act as vast population sinks, drawing in individuals from adjoining natural areas into places where they cannot survive, let alone successfully reproduce. Recently, moreover, artificial lighting has been demonstrated to have effects on the larval development of moth species, further implicating this source as a possible cause for declines in their populations (Boyce et al., 2021; Plummer et al., 2016). Roads with heavy night-time traffic may further contribute to this source of impacts, literally in this case (see Martin et al., 2018). Even single roads that parallel or bisect natural areas may have major effects on moth populations but the enormous increase in traffic associated with urban areas is likely to take a heavy toll.
- Runoff of landscaping chemicals, including pesticides. Of particular concern in this regard is the dispersion of neonicotinoids. This particular group of pesticides has been shown to travel through the soil and water far from their point of application. These are systemic pesticides that are taken up by plants where they can affect even the nectar and pollen of the plants, as well as the leaves. All insects that either eat foliage or visit flowers can, thus, be affected. In agricultural areas where the application of neonicotinoids has greatly increased over the past two decades, crashes in insect populations, including bees and butterflies, appear to be closely correlated (see Forister et al., 2016; Hopwood et al., 2016; and Coulson, 2021).
- Aerial spraying of broad-spectrum pesticides to control mosquito populations is another potential concern, particularly where a large human population has developed along the interface with large tracts of wetlands. We are not aware that any such spraying has been done in the New Hope watershed, but the potential definitely exists.
- Stormwater runoff from increased impervious surfaces associated with development. At least some of the increased flooding observed in the New Hope watershed may be due to urbanization, related specifically to the construction of houses, parking lots, roads, and other surfaces that do not allow rainwater to percolate down into the soil. While we do not believe that flooding by itself is responsible for all of the decline in moth populations in the study area, it is nonetheless likely to be playing at least some role.
- Introduction of exotic, invasive species. The most dramatic – i.e., the most visible – impacts to the New Hope Bottomlands are the destruction of Ash trees by the Emerald Ash Borer, a beetle species introduced from Asia. This impact alone may be responsible for the complete extirpation of six species of macro-moths, although this will need further surveys to verify (see Wagner and Todd, 2016). In the Northeast, the introduction of a parasitoid fly, *Compsilura concinnata*, to combat outbreaks of the moth *Lymantria dispar* (formerly known as the Gypsy Moth) has had major non-target impacts to a wide range of other moth species (see Wagner, 2012). This species has been moving steadily southward since its introduction into North America and is

expected to reach North Carolina. Large moths, such as Sphinx Moths, Giant Silk Moths, and Underwing Moths are among the most conspicuous victims, which, in fact were poorly represented in our moth collections in the New Hope Bottomlands. The reduction of many of the small litter- and lichen-feeding species, however, seems unlikely to be related to this specific cause.

- In the context of *Lymantria* control efforts, large tracts of bottomlands are regularly treated in the northeastern part of North Carolina using *Bacillus thuringiensis* (Bt) to suppress outbreaks of that moth. As documented in many studies, including one conducted here in North Carolina (Hall et al., 1999), use of this particular control agent can have devastating impacts to native, non-target species of moths and butterflies. Given that *Lymantria* can pop up virtually anywhere within the state, there is a good chance that it will eventually show up in the New Hope Bottomlands.

In reviewing these impacts as possible explanations for the decline in macro-moths that we believe has taken place in the New Hope Bottomlands, there are no clear answers. This is a common conclusion reached by a number of more detailed analyses. Blumgart et al. (2022), for instance used a detailed modeling approach to assess the importance of several potential causal agents, including several of those mentioned above. While they concluded that macro-moth decline in Great Britain was especially severe in broadleaf woodlands, they were unable to pinpoint any particular cause or a combination of them that could account for their findings.

In the case of the New Hope Bottomlands in particular, the possible causes must be capable of affecting the entire macro-moth fauna, from litter- and lichen-feeding species to canopy foliage-feeding species. Aerial spraying of broad-spectrum pesticides could have that type of impact but no such spraying appears to have taken place in this particular area. The possible effects of neonicotinoids could also be widespread, at least among foliage-feeding species and flower visitors, but many of the litter- and lichen-feeding species that have shown declines do not fit into those categories (unless dead leaves retain the pesticides in the case of the litter species). Neither would those species be expected to decline due to the browsing impacts of deer, nor are there any invasive exotics that we are aware of – including parasitoids – that are likely to be the source of decline in those groups of species.

That leaves light-pollution as a cause that could, in fact, affect all species of moths. Unlike the Orthoptera, which we described in their summary of the survey results as survive-in-place strategists, similar to plants, many species of moths rely on a metapopulation strategy to cope with locally-extirpating disturbance events, e.g., wildfires. That strategy, however, makes them particularly vulnerable to anything that disrupts their ability to disperse, which includes both fragmentation of their habitats and potentially anything that affects their ability to orient or otherwise control their movements during dispersal. Light pollution, more than any other factor that has so far been identified, seems to produce exactly those effects (see Coulson, 2021, for a discussion of radio-wave pollution and other hitherto unexplored possibilities).

As a test of the impacts of urbanization on adjoining natural areas, some of the floodplains that were surveyed in the past could be theoretically re-surveyed, looking for differences between areas that have experienced recent urbanization versus those that have not. Even surveying areas that have not experienced those types of changes – which is probably the case for most of the seven sites used in the comparisons presented above – would help to determine whether some other, very pervasive impacts to the macro-moth fauna have occurred in the years since these sites were last investigated. The bottom line is that more on-the-ground biodiversity surveys are crucially needed to help figure out exactly what is affecting native ecosystems so dramatically. Without that information, we can only offer general, rule-of-thumb recommendations for conservation efforts.

Conservation Recommendations

1. Use outdoor lighting that is designed to reduce impacts to nocturnal insects; avoid the use of mercury-vapor lights and others sources producing a high UV output. Maintain a forested buffer between developed areas and sensitive natural areas.
2. Discourage the use of neonicotinoid pesticides anywhere in the vicinity of sensitive natural areas.
3. Avoid the use of aerial application of broad-spectrum pesticides to suppress mosquito populations, particularly where they represent only temporary nuisances rather than significant carriers of diseases. Promote the draining of all outdoor sources of standing water to prevent the build-up of house mosquitos.
4. Use only highly specific control agents to combat any outbreaks of *Lymantria* that occur within the New Hope watershed. Follow the principals of Integrated Pest Management, suppressing outbreaks but not attempting total eradication.
5. Monitor trends in macro-moth diversity and abundance and continue to try to identify the specific causes of their decline in the New Hope Bottomlands.

References

Blumgart, D., Botham, M.S., Menéndez, R. and Bell, J.R., 2022. Moth declines are most severe in broadleaf woodlands despite a net gain in habitat availability. Insect Conservation and Diversity 15:496–509. Available online at: https://resjournals.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/icad.12578

Boyes, D.H., Evans, D.M., Fox, R., Parsons, M.S. and Pocock, M.J., 2021. Street lighting has detrimental impacts on local insect populations. Science Advances, 7(35):1-8. Available online at: https://www.science.org/doi/pdf/10.1126/sciadv.abi8322

Durham County Office of Sustainability, Department of Engineering and Environmental Services. Extreme precipitation and flooding. Accessed 2022-11-25. Available online at https://www.dconc.gov/county-departments/departments-a-e/engineering-and-environmental-services/sustainability-office/climate-resilience/excessive-precipitation)

Forister, M.L., Cousens, B., Harrison, J.G., Anderson, K., Thorne, J.H., Waetjen, D., Nice, C.C., De Parsia, M., Hladik, M.L., Meese, R. and van Vliet, H., 2016. Increasing neonicotinoid use and the declining butterfly fauna of lowland California. Biology letters, 12(8), p.20160475. Available online at: https://royalsocietypublishing.org/doi/full/10.1098/rsbl.2016.0475

Fox, R., 2013. The decline of moths in Great Britain: a review of possible causes. Insect Conservation and Diversity, 6(1):5-19. Available online at: https://www.boerenlandvogels.nl/sites/default/files/Decline-of-moths-in-GB-a-review-of-possible-causes.pdf

Goulson, D., 2021. Silent Earth: Averting the Insect Apocalypse. Random House. 328 pp.

Hall, S., Sullivan, J. and Schweitzer, D., 1999. Assessment of risk to non-target macromoths after Btk application to Asian Gypsy Moths in the Cape Fear region of North Carolina. USDA Forest Service, Morgantown West Virginia. FHTET-98-16, 95pp. Available online at: https://nc-biodiversity.com/sites/default/files/AGM%20Non-Target%20Impact%20Study%2C%20edited%20June%202017.pdf

Hallmann, C.A., Sorg, M., Jongejans, E., Siepel, H., Hofland, N., Schwan, H., Stenmans, W., Müller, A., Sumser, H., Hörren, T. and Goulson, D., 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PloS One, 12(10), p.e0185809. Available online at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0185809

Hopwood, J., Code, A., Vaughan, M., Biddinger, D., Shepherd, M., Black, S.H., Lee-Mäder, E. and Mazzacano, C., 2016. How neonicotinoids can kill bees. The Science Behind the Role These Insecticides Play in Harming Bees. Portland, OR: Xerces Society for Invertebrate Conservation. Available online at: https://www.xerces.org/sites/default/files/2018-05/16-022_01_XercesSoc_How-Neonicotinoids-Can-Kill-Bees_web.pdf

Lister, B.C. and Garcia, A., 2018. Climate-driven declines in arthropod abundance restructure a rainforest food web. Proceedings of the National Academy of Sciences, 115(44), pp.E10397-E10406. Available online at: https://www.pnas.org/doi/full/10.1073/pnas.1722477115

McCabe, T.L., 1981. *Clemensia albata*, an algal feeding Arctiid. Journal of the Lepidopterists Society, 35(1):34-40.

Martin, A.E., Graham, S.L., Henry, M., Pervin, E. and Fahrig, L., 2018. Flying insect abundance declines with increasing road traffic. Insect Conservation and Diversity, 11(6):608-613. Available online at: https://carleton.ca/glel/wp-content/uploads/18MartinetalInsectConDiv.pdf

Plummer, K.E., Hale, J.D., O'Callaghan, M.J., Sadler, J.P. and Siriwardena, G.M., 2016. Investigating the impact of street lighting changes on garden moth communities. Journal of Urban Ecology, 2(1). Available online at: https://academic.oup.com/jue/article/2/1/juw004/2624137

Sánchez-Bayo, F. and Wyckhuys, K.A., 2019. Worldwide decline of the entomofauna: A review of its drivers. Biological conservation, 232:8-27. Available online at: https://www.boerenlandvogels.nl/sites/default/files/2019-02/Sanchez-Bayo%20%26%20Wyckhuys%202019.pdf

Wagner, D.L., 2012. Moth decline in the northeastern United States. News of the Lepidopterists' Society, 54(2):52-56. Available online at: https://www.lepsoc.org/sites/all/themes/nevia/lepsoc/Conservation%20Matters%20-%20Moth%20decline.pdf

Wagner, D.L., Grames, E.M., Forister, M.L., Berenbaum, M.R. and Stopak, D., 2021. Insect decline in the Anthropocene: Death by a thousand cuts. Proceedings of the National Academy of Sciences, 118(2), p.e2023989118. Available online at: https://www.pnas.org/doi/full/10.1073/pnas.2023989118

Wagner, D.L. and Todd, K.J., 2016. New ecological assessment for the Emerald Ash Borer: a cautionary tale about unvetted host-plant literature. American Entomologist, 62(1):26-35. Available online at: https://academic.oup.com/ae/article/62/1/26/2194528

Micro-moths and Leaf-mining Flies, Beetles, and Sawflies

Biology and Characteristics

Micro-moths are an informal taxonomic group that consists of mainly small to minute moths. A small percentage are quite large, however, and the main definition of this group is that they comprise all lepidopteran species other than butterflies and the macro-moths. Unlike the macro-moths, which are a monophyletic group that consists of several related superfamilies, the micro-moths are extremely diverse taxonomically. They include the most primitive groups of living moths, some of which possess chewing mandibles instead of a tubular proboscis that otherwise typifies the Lepidoptera. At the other end of the evolutionary scale are groups of micro-moths that are the closest relatives of the butterflies, and others that are closely related to the macro-moths.

Many of the micro-moths are extremely small, with wing lengths of only a couple of millimeters. They have been more difficult to study than the larger macro-moths due to a scarcity of modern taxonomic revisions, and because identification often requires the dissection of specimens to examine genitalia. Unlike the macro-moths, many are not strongly attracted to lights.

The emergence of digital photography, affordable macrophotography equipment, and an army of citizen scientists has produced an explosion of interest in the micro-moths. Many species are spectacularly colored and patterned, and the development of websites such as the Moth Photographers Group, BugGuide, iNaturalist, and the Moths of North Carolina have provided a venue for both citizen scientists and professional lepidopterists to post tens of thousands of new records. These have greatly improved our understanding of the distribution, natural history, and ecology of this group.

These changes in the popularity of micro-moths are reflected in trends seen in the Moths of North Carolina website. In the year 2000, our database contained records for 1,428 species, including 1,200 macro-moths and 228 micro-moths. In 2010, the total increased to 1,761 species, with 1,297 macro-moths and 464 micro-moths. With a much-increased focus on micros during the last decade, the state total as of December, 2020 was 2,736 species, with 1,409 macros and 1,327 micros. New additions to the state fauna since 2020 (currently at 2,873 species) have almost all been micro-moths.

Many of the micro-moths have distinctive life histories that are either uncommon or do not occur in the macro-moths. One important group are leaf-mining species, where the minute larvae spend part or all of their larval period inside of leaves where they feed between the cellular layers. As they feed and burrow through the leaves, they leave distinctive feeding tracks that can be used -- along with the identity of the host plants -- to identify them to species.

There are thought to be over 1200 leaf-mining moths in North America, with hundreds of species that are undescribed.

Other micro-moths have different ecological lifestyles and often leave signals of their presence. For example, some mine or bore into the stems or fruits of plants, while others build distinctive larval shelters by folding or binding leaves together. Many of the micro-moths are specialists that feed on a single species of plant or just on a single genus. Their high degree of host specificity makes them a rich target for ecological studies. For all these reasons, we have treated this group separately from the macro-moths and the butterflies.

In addition to lepidopteran leaf miners, species of flies and beetles that have leaf- or stem-mining larvae were included in this survey. A few gall-forming species were also included, all of which can be surveyed during the day using similar search techniques.

Survey Efforts

No prior surveys have been conducted within the project area for moths in general. During the current project, surveys for leaf-mining species were conducted by Jim Petranka on 2021-09-29 and by Tracy Feldman on 25 dates from April 1, 2022 to October 10, 2022. Most observations were made in the New Hope Bottomlands and far fewer in the Hollow Rock Nature Park. A very few were also obtained from the Mt. Moriah Bottomlands and Mud Creek Bottomlands.

Although many micro-moths are not attracted to lights, many others are and regularly appear on sheets or light traps that are fitted with UV-lights. Light traps were used for moth collecting more generally by Steve Hall on six dates in 2022 in the New Hope Bottomlands and yielded numerous micro-moths. For details regarding trapping efforts, see the summary for the macro-moths. Bo Sullivan dissected many of the micro-moth species that were collected in the trap samples and confirmed their identities using genitalia.

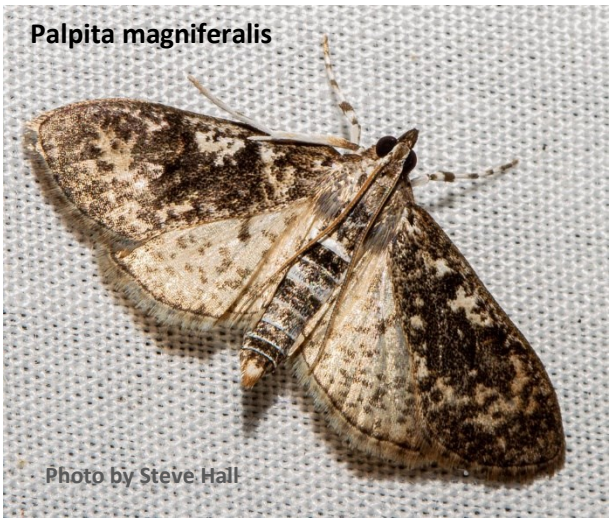
Summary of the Micro-moth and Other Leaf-mining Species Recorded During the Project

The 237 species of micro-moths documented during this study comprise 59.5% of all moth species that were observed. Together with 161 macro-moth species and the 37 species of butterflies, the 435 species of lepidopterans were the most species-rich group of any that were included in the survey.

Beetles and flies, unfortunately, did not get the same thorough treatment as the moths and each would likely have yielded a similar or even greater number of species. Several species in

these orders, however, were recorded in the general survey that we conducted of leaf-mining species and are included in this report. These include four species of leaf-mining beetle species and 28 species of leaf-mining flies (representing two families); two species of leaf-mining sawflies were also recorded (see Appendix 15 for a complete list). Overall, this particular survey produced dozens of new county records and helped to clarify the distribution and abundance of a number of species within North Carolina. Several undescribed species that we discovered during the project are among the most noteworthy species found in this project.

Noteworthy Species



Noteworthy species of micro-moths and other leaf-mining species include those that appear to be of clear conservation concern based on knowledge of specific threats or observations of downward population trends. This category includes two ash-feeding: *Marmara fraxinicola*, a stem miner, and *Palpita magniferalis*, a leaf-rolling species. Both of these species, along with nearly 100 other species of insects in the eastern United States that are highly dependent on ash or fringetree, are being massively decimated by attacks from the introduced Emerald Ash Borer (see Wagner and Todd, 2016). Of the nine species of ash-dependent moths recorded in our area, these two species were the only ones documented in the survey. Both may be able to use ash saplings, which are still common in the study area, but the reasons explaining their continued survival remain to be determined.

One other species that is similarly threatened due to impacts to its host plant is *Ancylis semiovana*. This species is a narrow specialist on New Jersey Tea (*Ceanothus americanus*), one of hundreds of species of herbaceous understory plants that have declined statewide due to overgrazing by deer. A single specimen was collected in the light-trap sampling and represents our only record for this species outside of the Blue Ridge Mountains. New Jersey Tea, itself, was not documented in the survey, nor were either of the other two *Ceanothus*-associated lepidopterans (one butterfly and one macro-moth) that have been recorded in the Piedmont.

Other noteworthy species include those that appear to be rare even though their host plants populations appear to be stable. One such species is *Omphalocera cariosa*, whose larvae feed on Canada Moonseed (*Menispermum*

canadense), a species associated with rich bottomlands and state-listed as S4. Despite the wide distribution of its host plant, we have only two state records for this moth. Other species falling into this category include *Cosmopterix teligera, Stigmella intermedia, and S. rosaefoliella*, which are specialists on grasses, sumacs, and roses, respectively. The causes for their rarity again are a mystery, since their host plants are all widespread in the state.

Other species that can be considered noteworthy are those that were recorded for the first time either in the state as a whole or within just the eastern Piedmont. In the case of these micro-moths, the actual rarity of the species still needs to be determined through much more systematic surveys of this group covering the entire state. Nonetheless, these discoveries represent definite advances in our knowledge of this group.

One species that was collected for the first time in North Carolina during the New Hope survey is *Anacampsis consonella*. Two others that were nearly the first state records are *Coptotriche purinosella* (first recorded only one month previously in Orange County) and *Helcystogramma hystricella* (first found earlier in the same month in Guilford County). Two other species, *Phyllonorycter ostryaefoliella* and *Mompha argentimaculella*, both found by Tracy Feldman at Leigh Farm Park (see below), were also new state records from the New Hope corridor in Durham County. Other species that appear to be rare in the eastern Piedmont include the following species that have several records in the Blue Ridge but are so far known only in our area from specimens collected in the New Hope Survey: *Dichomeris caia, Ancylis semiovana, Cameraria obstrictella, Cosmopterix clandestinella,* and *Olethreutes concinnana*.

One other group of noteworthy species are those that appear to be new to science, i.e., yet to be formally described. These include several species of leaf-miners that were documented by Tracy Feldman either in the current survey or in surveys he previously (2015-2021) conducted at the Leigh Farm Park, a site located on the slopes adjacent to the New Hope floodplain 1.7 miles south of the current project area.

One such species is a stem miner in the genus *Marmara*, reared first from specimens collected on Box Elder during the current survey. If it is confirmed as a new species, it will be described from this material; this specimen will consequently be the type specimen for the species. Two others that have been found so far only in the New Hope Bottomlands include another species of *Marmara* and a leaf-mining fly in the genus *Ophiomyia*. Overall, thirteen unknown moth species have been recorded for the first time in the Durham County portion of the New Hope corridor, from Hollow Rock to Leigh Farm Park. Nine of these species were recorded in the current survey.

Overall Quality of the Micro-Moth Community and Comparison to Other Sites

Because micro-moths have been neglected historically, there have been only a few site-focused surveys of this group that have been done in North Carolina. Two sites where comparable

surveys of micro-moths have been done[2] and include similar habitats are Leigh Farm Park and Sandy Creek Park. Both, however, are also located in the New Hope Creek watershed and located only a mile or so away from the project area. Even though they represent essentially the same faunal unit, comparisons between these three sites seem worthwhile to examine for the consistency of their results.

First, far more species of micro-moths were recorded in the current survey than at the other two sites: 232 vs. 74 species. This is largely due to the use of light traps in the current project but not at the others. Limiting the comparison solely to families of leaf-mining species (Nepticulidae, Heliozelidae, Lyonetiidae, Gracillariidae, and Momphidae), 40 species were recorded in the New Hope project but not found at the other two sites. Of these species, 6 are associated with rich, wet hardwood forests, the most distinctive habitat found in the study area. Conversely, of seven species recorded at Leigh Farm or Sandy Creek but not in the New Hope study area, all are associated primarily with upland habitats. Of the 19 species that were common to the New Hope project area and the other sites, only one species -- Ectoedemia platanella, a sycamore-feeding species – is associated with rich, bottomland hardwood habitats. Three others are willow-feeding species, which reflects the wetland conditions that exist in all of these areas.

Although the level and types of sampling are different between these areas, we at least found some support for the richness of the New Hope study area in terms of leaf-mining moths most indicative of its dominant habitat features. This is also consistent with the general lack of rich bottomlands at the other two sites. Sandy Creek does not have the same input of rich sediments as found along the main stem of New Hope Creek and Leigh Farm is located up on slopes above the New Hope floodplain, which at that point has been drastically altered by the presence of waterfowl impoundment.

Conservation Concerns

We suspect that most of the factors that are responsible for the paucity of macro-moths in the New Hope Bottomlands are affecting the micro-moths as well. In addition to loss of specific host plants, as in the case of the ash-feeding species, many leafminers overwinter in fallen leaves on the forest floor and are vulnerable to losses from flooding. Other factors that can adversely affect micro-moths include invasive plants, browsing by deer, and the broadscale use of herbicides along roadways and powerline corridors.

Invasive plants frequently outcompete and replace native plants that serve as hosts. Our native moths evolved to exploit native plants, and invasives such as Chinese Privet and Japanese Stilt-grass are almost never used as a food source. Deer can have a major impact on leafminers and other species by directly removing shrubs and herbaceous plants that serve as hosts. Many

[2] These surveys have been conducted by a number of different people but including Tracy Feldman and Brian Bockhahn, who contributed to the current New Hope project.

forests in North Carolina are heavily overgrazed, with most of the herbaceous ground cover that micro-moths depend on eliminated.

Many micro-moths are attracted to lights and the increased traffic volume that has occurred during the last few decades in North Carolina has undoubtedly adversely affected many populations. Increases in the number of building and street lights from urban development in the region has also taken its toll (see the detailed discussion of factors affecting moths under the macro-moth account, many of which are applicable to the micro-moths).

Conservation Recommendations

1. Use outdoor lighting that is designed to reduce impacts to nocturnal insects; avoid the use of mercury-vapor lights and others sources producing a high UV output. Maintain a forested buffer between developed areas and sensitive natural areas.
2. Discourage the use of neonicotinoid pesticides anywhere in the vicinity of sensitive natural areas.
3. Avoid the broadscale application of herbicides in powerline rights-of-way and other corridors.
4. Avoid the use of aerial application of broad-spectrum pesticides to suppress mosquito populations, particularly where they represent only temporary nuisances rather than significant carriers of diseases. Promote the draining of all artificial outdoor sources of standing water (e.g., clogged gutters; water-filled cans and buckets) to prevent the build-up of house mosquitos.
5. Use only highly specific control agents to combat any outbreaks of *Lymantria* that occur within the New Hope watershed.
6. Control invasive plants that are on site.
7. Monitor trends in micro-moth diversity and abundance.

References

Eiseman, C. 2019. Leaf Miners of North America. First Edition (June edition). ebook; self-published

Eiseman, C.S., Davis, D.R., Blyth, J.A., Wagner, D.L., Palmer, M. W. and T.S. Feldman. 2017. A new species of Marmara (Lepidoptera: Gracillariidae: Marmarinae), with an annotated list of known hostplants for the genus. Zootaxa 4337:198-222.

Wagner, D.L. and Todd, K.J., 2016. New ecological assessment for the Emerald Ash Borer: a cautionary tale about unvetted host-plant literature. American Entomologist, 62(1):26-35. Available online at: https://academic.oup.com/ae/article/62/1/26/2194528

Bees

Biology and Characteristics

Bees are best known for their ecological role as pollinators. Adult bees of both sexes visit flowers to consume nectar and pollen, and female bees visit additional flowers to collect pollen as food for their larvae. During this process, pollen is transferred from flower to flower, effecting pollination. Globally, about 87% of flowering plants benefit from animal pollination, and in most cases, bees are the most efficient of the animal pollinators (Ollerton et al. 2011).

Bees are central-place foragers, meaning they invest in nest construction and only forage within a limited radius from the nest (Gathmann and Tscharntke 2002). Thus, their activity is restricted to areas that provide suitable nesting and foraging resources within their foraging range. Although some large species–such as bumble bees, carpenter bees, and honey bees–can fly for many km, most native bees have typical foraging ranges less than 1-2 km from their nests (Gathmann and Tscharntke 2002; Greenleaf et al. 2007).

The specific resources used for nesting and foraging vary among species. In terms of diet, bees may be specialists that rely on a single family or genus of plants for pollen, versus generalists that benefit from access to pollen from a wide range of plant taxa (Michener 2007). In terms of nesting, species may dig tunnels underground, nest in pre-existing tunnels in stems and wood, or occupy other pre-existing cavities such as rodent burrows or bird nests (Michener 2007).

Bees are most often associated with open habitats such as prairie and savannah where floral resources are abundant (Michener 2007). Woodland species are typically associated with spring ephemerals that bloom before canopy closure (Smith et al. 2019), and these bees are active only in spring, then dormant for the rest of the year. Given the forested environment in much of the New Hope Bottomlands, we expected early spring to yield the greatest bee diversity and any species of conservation interest; in the summer and fall, we expected that disturbed areas (parking lots and utility rights of way) to be the main open habitats, but that these would host relatively common, urban species.

Because of their strong seasonality and annual variation in population sizes, a thorough bee inventory requires intensive sampling (monthly or biweekly) over multiple years. Thus, the current survey should be considered a very incomplete preview of the bee fauna of the New Hope Bottomlands.

Survey Efforts

We visited the New Hope Bottomlands on five dates during the survey period and used a combination of active searching and passive traps. Active searches allow specimens to be associated with the floral resources the bee was using; passive traps may detect species that are missed during active searches. Sampling efforts are summarized below (*Table 1)*.

In most cases we collected specimens to confirm identification, but a few large and common species were identified in the field without retaining specimens. Specimens will be deposited in the NCSU Insect Museum, but it is currently not accepting specimens until new staff are hired. In the meantime, specimens are stored in the Youngsteadt Lab at NCSU.

Table 1. Sampling effort

Date	Location	Method	Time of day	Who
Oct 8, 2021	Old Ch. Hill. Rd. Park	Active search	10:00 - 14:00	HKL & EY
Mar 18, 2022	Old Ch. Hill. Rd. Park	Active search	11:00 - 13:30	HKL & EY
Mar 18, 2022	Old Ch. Hill. Rd. Park	Pan traps (30)	3/18 12:00 - 3/19 13:00	HKL & EY
Mar 18, 2022	Hollow Rock Park	Active search	13:45 - 15:20	HKL & EY
Mar 18, 2022	Hollow Rock Park	Pan traps (30)	3/18 14:00 - 3/19 14:00	HKL & EY
Apr 1, 2022	Old Ch. Hill. Rd. Park	Active search	14:30 - 15:00	HKL & EY
Apr 1, 2022	Old Ch. Hill. Rd. Park	Pan traps (30)	13:00 - 15:00	HKL & EY
Apr 1, 2022	Hollow Rock Park	Active search	12:15 - 14:05	HKL & EY
Apr 1, 2022	Hollow Rock Park	Pan traps (30)	12:30 - 14:00	HKL & EY
Jul 2, 2022	Old Ch. Hill. Rd. Park	Active search	12:20 - 3:20	NLA
Jul 22, 2022	Old Ch. Hill. Rd. Park	Active search	8:55 - 10:20; 11:30 - 12:30	HKL & EY
Jul 22, 2022	Hollow Rock Park	Active search	10:30 - 11:00	HKL & EY

Summary of the Bee Species Recorded During the Project

We recorded a total of 301 individual observations, of which 196 (65%) have a physical specimen and 285 (95%) have been identified to species using Ascher & Pickering (2016), Mitchell (1960, 1962), Gibbs (2011), and comparison to reference material in the NCSU Insect Museum (*Table 2*).

The total number of species observed was 42. The asymptotic species richness estimator (Chao and Chiu 2016; Hsieh et al. 2016) was 56 species (SE = 14), suggesting that if we continued to sample additional site/date combinations we would detect additional species (*Fig. 1*).

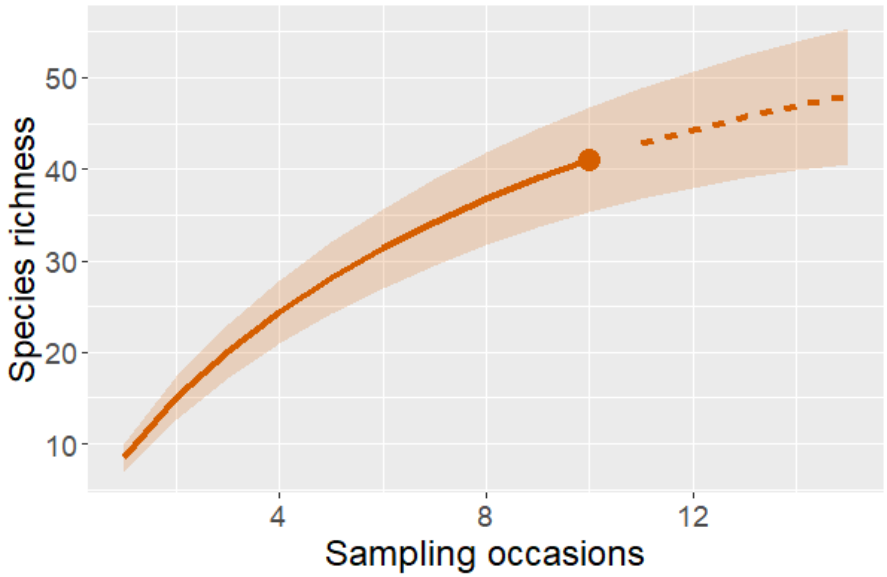


Fig. 1. Rarefaction curve showing species richness ± SE as samples accumulate, where each sampling occasion is a single site-date combination. The dotted line represents extrapolated species richness if sampling were to continue. The curve has not reached an asymptote, indicating that sampling is still incomplete.

Table 2. Bee species observed in two parks in the New Hope Bottomlands; values are number of specimens collected/observed at each site in fall 2021 (fa), spring 2022 (sp) or summer 2022 (su). Deeper green color highlights more abundant observations.

		Old Chapel Hill Rd Park				Hollow Rock Park	
Family	Species	fa	sp	su		sp	su
Andrenidae	Andrena cressonii		2				
	Andrena erigeniae		31			18	
	Andrena macra					1	
	Andrena nasonii					3	
	Andrena violae		4			3	
	Andrena sp.		2				
	Panurginus potentillae		1				
Halictidae	Augochlora pura	1					
	Augochlorella aurata		2	1			
	Lasioglossum fuscipenne					1	
	Lasioglossum bruneri		3			3	
	Lasioglossum callidum					1	
	Lasioglossum cressonii		2			11	
	Lasioglossum imitatum	3	3				

		Old Chapel Hill Rd Park				Hollow Rock Park	
Family	Species	fa	sp	su		sp	su
	Lasioglossum oblongum		1	1			
	Lasioglossum weemsi		2				
	Lasioglossum sp.	1					
Megachilidae	Coelioxys octodentata	1					
	Coelioxys sayi			1			
	Megachile exilis	1					
	Megachile mendica	3		3			1
	Megachile xylocopoides			1			1
	Megachile sp.	2					
	Osmia atriventris		12			13	
	Osmia georgica		2				
	Osmia lignaria					4	
	Osmia pumila		8			11	
	Osmia sandhouseae		1				
	Osmia taurus		7			6	
	Osmia sp.		4				
Apidae	Apis mellifera	32				3	
	Bombus bimaculatus					2	
	Bombus griseocolis	2					
	Bombus impatiens	38		1			
	Ceratina calcarata		1				
	Ceratina dupla	1		1			
	Ceratina strenua			1			
	Eucera atriventris		1				
	Habropoda laboriosa		1				
	Melissodes comptoides	1					
	Melissodes trinodis			2			

		Old Chapel Hill Rd Park				Hollow Rock Park	
Family	Species	fa	sp	su		sp	su
	Nomada imbricata/luteoloides		3			3	
	Nomada pygmaea		3			3	
	Nomada sp.		2				
	Ptilothrix bombiformis			2			
	Stelis louisae			1			
	Xylocopa virginica	13		1			

Noteworthy species

We detected several specialist bees that require particular plant families or genera as pollen sources: *Andrena erigeniae* (*Claytonia;* Fig. 2), *Andrena violae* (*Viola*), *Panurginus potentillae* (*Potentilla*), *Melissodes trinodis* (*Asteraceae*), and *Ptilothrix bombiformis* (*Hibiscus, Ipomoea*). *P. potentillae* is relatively infrequently collected. *A. erigeniae*, while common, is not ubiquitous, because of its obligate relationship with *Claytonia*. The rest are common and widespread species.

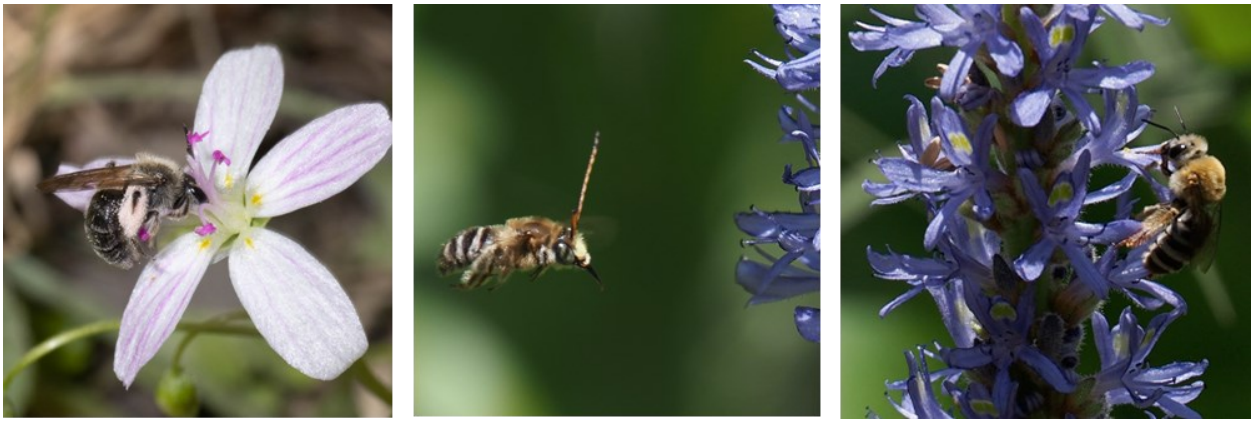


Fig. 2. Andrena erigeniae *visiting spring beauty (*Claytonia virginica*),* Melissodes *male (center) and* Melissodes *female (right) visiting pickerel weed (*Pontederia cordata*). Photos: Stephen P. Hall (left), Nancy L. Adamson (center, right).*

We also collected a number of parasitic bee species, indicative of robust host populations: *Coelioxys octodentatus* and *Coelioxys sayi* (hosts are *Megachile mendica, Megachile brevis, Megachile rotundata*), *Stelis louisae* (host is *Megachile campanulae*), and *Nomada* species (hosts are typically *Andrena*, consistent with the high abundance of A. erigeniae).

Two non-native bee species were found: *Apis mellifera* and *Osmia taurus*; the latter is more recently introduced (first recorded in the US in 2002; LeCroy et al. 2020) and invasive. Although *A. mellifera* was detected mainly in the parking lot of Old Chapel Hill Road Park, *O. taurus* was

common on *Vaccinium* at the forest edge. Please see additional discussion under conservation concerns, below.

Overall Quality of the Bee Community and Comparison to Other Sites

The bee community documented at New Hope is typical of the region and expected based on sampling effort. While most of the dataset consists of commonly occurring species, we did detect a few less ubiquitous species (e.g., *Panurginus potentillae*, *Stelis louisae*). This further suggests that with more frequent sampling carried out over a longer period of time, more species would be detected within this community (*Fig. 1*). As many spring ephemeral flowers have short blooming periods, it is likely that we missed the sampling window for some of these species and their associated pollinators (we unfortunately missed *Erythronium*, for example).

The estimated asymptotic richness (about 56 species) represents about 10% of the bee diversity of the state. Based on historic records and ongoing projects, Wake County has records for more than 300 species (Ruzi et al. unpublished); suggesting again that more species could be found in this area. However, we do not yet have checklists available for Durham and Orange counties for comparison.

Conservation concerns

The detection of non-native species should be of concern as these species can harm wild, native bee communities. In particular, *Osmia taurus* has caused declines in native *Osmia* populations, with reductions as high as 91% documented in some cases (LeCroy et al. 2020). While the specific reasons why *O. taurus* is displacing native species are not known, possible reasons include competition for resources, habitat changes, and pathogen sharing. Pathogen sharing is a concern with many introduced species and has been a topic of great focus in regards to *Apis mellifera* (Ravoet et al. 2014). While pathogen spread from *A. mellifera* to native species has not been detected in North Carolina (Levenson and Tarpy, 2022), it is possible and could be instigated if bee species do not have access to sufficient resources.

Some of the species detected in New Hope (e.g., *Stelis louisae*), while not rare per se, are more commonly detected in some habitat types than others. For example, in research conducted in agricultural areas across NC, *Stelis* species were never detected (Levenson et al. 2022). However, in projects conducted in urban areas and game lands in the NC Piedmont (Youngsteadt, unpublished data), *Stelis* is detected regularly. As different bee species are more common in some habitats versus others, this highlights the need to preserve and protect all habitat types in order to support the full bee community of NC.

References

Ascher, J.S. and Pickering, J. (2016). Discover Life Bee Identification Guides. Available at: https://www.discoverlife.org/mp/20q.

Chao, A. and Chiu, C.H. (2016). Species Richness: Estimation and Comparison. *Wiley StatsRef: Statistics Reference Online*. 1-26.

Gathmann, A. and Tscharntke, T. (2002). Foraging ranges of solitary bees. *Journal of Animal Ecology*, 71: 757-764.

Gibbs, J., (2011). Revision of the metallic *Lasioglossum* (*Dialictus*) of eastern North America (Hymenoptera: Halictidae: Halictini). *Zootaxa*, 3073:1-216.

Greenleaf, S.S., Williams, N.M., Winfree, R., and Kremen, C. (2007). Bee foraging ranges and their relationship to body size. *Oecologia*, 153: 589-596.

Hsieh, T.C., Ma, K.H., and Chao, A. (2016). iNEXT: an R package for rarefaction and extrapolation of species diversity (Hill numbers). *Methods in Ecology and Evolution*, 7: 1451–1456.

LeCroy, K.A., Savoy-Burke, G., Carr, D.E., Delaney, D.A., and Roulston, T.H. (2020). Decline of six native mason bee species following the arrival of an exotic congener. *Scientific Reports*, 10:18745.

Levenson, H. and Youngsteadt, E. (2019). The Bees of North Carolina: An Identification Guide. *NCSU Extension*.

Levenson, H.K., Sharp, A.E., and Tarpy, D.R. (2022). Evaluating the impact of increased pollinator habitat on bee visitation and yield metrics in soybean crops. Agriculture, Ecosystems and Environment, 331: 107901.

Levenson, H.K. and Tarpy, D.R. (2022). Effects of planted pollinator habitat on pathogen prevalence and interspecific detection between bee species. *Scientific Reports*, 12: 7806.

Michener, C.D. (2007). The Bees of the World - 2nd Ed. *The Johns Hopkins University Press*. Print.

Mitchell, T. B. (1960). Bees of the Eastern United States. Part I. North Carolina Agricultural Experiment Station, Raleigh, NC.

Mitchell, T. B. (1962). Bees of the Eastern United States. Part 2. North Carolina Agricultural Experiment Station, Raleigh, NC.

Ollerton, J., Winfree, R., and Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos*, 120: 321-326.

Ravoet, J., De Smet, L., Meeus, I., Smagghe, G., Wenseleers, T., and de Graaf, D.C. (2014). Widespread occurrence of honey bee pathogens in solitary bees. *Journal of Invertebrate Pathology*, 122: 55 - 58.

Smith, C., Weinmann, L., Gibbs, J., Winfree, R. (2019). Specialist foragers in forest bee communities are small, social or emerge early. *Journal of Animal Ecology*, 88: 1158-1167.

Beetles

Biology and Characteristics

Beetles are one of the most diverse groups of species on the planet, with more species described in this order (Coleoptera) than for any other single taxonomic group. Along with the Lepidoptera, Diptera, and Hymenoptera – the Big Four in terms of insect diversity – beetles are members of the Holometabola, i.e., species that undergo what is termed complete metamorphosis. Their larvae are all relatively sedentary, being specialized for feeding rather than dispersal, for which the adults are specialized. Many beetle larvae – "grubs" –exist completely encased within their food sources, which is wood in a large number of species, but also includes dead vertebrates, in the case of carrion beetles, or vertebrate wastes, in the case of dung beetles.

A main adaptation of the adults that distinguishes them from other insects is the extremely thick and hardened pair of forewings. These serve to protect the membranous hindwings which are the only pair that functions in flight for this group. The high degree of protection offered by their armor allows the adults to burrow into the earth or wood without the damage that would occur to species with membranous forewings.

Together, the features of the larvae and adults of the beetles have enabled them to become the most diverse group of wood-dwelling insects, with many species feeding on dead or dying trees, with some, like the Emerald Ash Borer, attacking living trees. Along with the carrion beetles and dung beetles, the wood-feeding beetles represent one of the most important groups of animals serving the crucial ecological role of detritivory. Other groups, however, are important predators of other insects and there are also a large number of flower-, foliage-, and seed-feeding species. Along with flies (Dipterans), beetles are one of the most ecologically diverse taxa in all of their ecosystems.

Survey Efforts

Although highly diverse, extremely numerous, and found in all terrestrial and freshwater ecosystems, their ability to take shelter inside logs, beneath bark, or under rocks makes them fairly cryptic, with a large number of sampling techniques required to either observe the species or obtain specimens. Because of the high degree of diversity within genera and families, taxonomists and ecologists specializing on beetles usually focus on just a small portion of the overall beetle fauna. In our efforts to create a Beetles of North Carolina website, we have focused on just a very few families, mainly those that are either diurnally active, such as the Tiger Beetles, or that come to lights at night and can be observed using sheet sampling or UV traps. The Longhorn Beetles (Cerambycidae) fall into this second group and also have many species that are active flower-visitors during the day. One other group that we have just begun to focus on are the Lampyrids, popularly known as fireflies or lightening bugs. Although mainly nocturnal, the lights they produce for courtship purposes make them conspicuous, with the

patterns of their flashes serving to identify them to species similarly to the calls made by singing members of the Orthoptera.

Tiger beetles and flower-feeding Long-horns were surveyed opportunistically and night-flying species were collected in the same light traps used for sampling moths. These surveys were mainly conducted by Steve Hall, with John Petranka also providing a number of records for diurnally active species. Clyde Sorenson made one survey trip to Hollow Rock to sample fireflies and Tracy Feldman provided records for species that have leaf-mining larvae.

Summary of the Beetle Species Recorded During the Project

Compared to their diversity and ubiquity, the results of our sampling efforts were extremely poor. Only 21 species were recorded, all of which are listed in Appendix 15, which otherwise includes species that were not specifically targeted in this survey.

Only a single species of tiger beetle – the common forest-inhabiting Six-Spotted Tiger Beetle, was observed. Although an effort was made to sample the sand and silt bars along New Hope Creek for riparian species, none were found. Nor were any of the upland species found along the trail that runs along the western edge of the project area that has been recently opened up due to development.

Likewise, only a very few species of longhorns were collected in the light trap samples or were observed at flowers. Only a total of three species of firefly were recorded on the one sampling visit made for that group, probably due to the dry conditions that had developed at the end of the summer. Only a few species of leaf-mining beetles were recorded, with their identification to species still pending.

Noteworthy Species

Nearly all of the species observed are common and typical of the habitats found in the study area.

Conservation Concerns

Three species of beetles are strongly associated with ash and are hence threatened with extirpation due to the impacts of the Emerald Ash Borer. One, in fact, is a bark-feeding species, *Agrilus subcintus*, in the same genus as the Emerald Ash Borer. According to Robert Haack & Toby Petrice, US Forest Service (BugGuide, accessed 2022-12-21), this species feeds primarily on dead twigs of ash and may actually show an initial increase following the attacks of the Emerald Ash Borer. However, after its food quality declines, this species is expected to show severe population crashes just a few years after the ashes themselves have been killed.

The other two beetles that may also be eliminated are among our largest and most spectacular of our insects, the Eastern Hercules Beetle (*Dynastes tityus*) and the Rhinoceros Beetle (*Xyloryctes jamaicensis*). Both congregate at ash trees for mating, with the males apparently using the sap produced by chewing the twigs of ash as an attractant for the females. Even though their larvae do not appear to be dependent on ash, the mating behavior of the adults appears to be putting these species at High Risk of Endangerment due to the ongoing destruction of ash forests (Wagner and Todd, 2016). Both of these species come to light to some extent but none were captured during the survey.

References

Wagner, D.L. and Todd, K.J., 2016. New ecological assessment for the emerald ash borer: a cautionary tale about unvetted host-plant literature. American Entomologist, 62(1):26-35. Available online at: https://academic.oup.com/ae/article/62/1/26/2194528 .

Amphibians

Biology and Characteristics

Amphibians are the oldest group of the tetrapods, the mainly four-legged species of vertebrates that first ventured onto land. The name “amphibia” – meaning two lives -- refers to the fact that most members of this class have different habitat requirements for their larvae and adults, a vestige of their aquatic ancestry. Among vertebrates, the radical transformation between larval and adult stages is essentially unique although it is common in insects and other groups of invertebrates.

North Carolina stands out as one of the global centers of biodiversity for amphibian species. This is particularly true for salamanders, with 63 species currently recognized in the state (see Amphibia of North Carolina website). The majority of these belong to the Plethodontidae, the Lungless Salamanders, and has its concentration in the Blue Ridge Mountains with 38 species. North Carolina and other regions of the Southeast also have the highest diversity of salamanders at the family level in the world, with members of the Cryptobranchidae, Proteidae, Amphiumidae, Plethodontidae, Sirenidae, Ambystomatidae, and Salamandridae all found here. With the exception of the Hellbender, which is confined to the Blue Ridge, the rest of these families are concentrated in the Coastal Plain. The same is true for frog species, which are also quite diverse, with 31 species and five families found in the state. No other region in the country has this range of species and families, which is a testament to the long stability and nearly unique combination of our vast and ancient coastal wetlands and mesic mountain forests.

Although there are a few groups of amphibians – e.g., members of the woodland salamander genus *Plethodon* -- that have become fully terrestrial breeders, most still require an aquatic habitat for their eggs and larval development. In some cases, adults may live in quite different habitats than their immature stages. Some species of treefrogs, for instance, spend most of their adult lives up in the tree canopy whereas their larvae require at least seasonal pools for their development. Migration between adult and larval habitats is a major fact of life for many of these species. Their habitat requirements can, therefore, be quite complex. Any conservation planning for this group of species needs to provide suitable habitat for both the aquatic and terrestrial stages of the life cycle.

Amphibians play key roles in the ecosystems they inhabit, where they often occur at much higher densities than other vertebrates. They are important prey for many larger predators, including a wide array of fish, reptile, mammal, and avian species, as well as other amphibians They can also play major roles as predators since the adults are secondary consumers that feed on other species of animals. Salamander larvae are also predators, while frog tadpoles typically feed on algae or aquatic species of vascular plants. Most adult amphibians and the larvae of salamanders feed voraciously on insects and other invertebrates. They are thus involved as

biological controls on the populations of their prey species and are themselves heavily dependent on the health of their prey species for their own survival. The same is true for their own set of predators. These key trophic interactions, in addition to the complex life histories and habitat requirements of amphibians, need to be considered not only to formulate plans for their own conservation, but equally, if not more importantly, the conservation of their ecosystems as well.

Survey Efforts

Amphibians were previously surveyed in the study area as part of the Durham County wildlife survey (Hall, 1995). For access reasons, however, as well as the much broader geographic scope of that project, surveys were done mainly in the Mt. Moriah Bottomlands and the Old Chapel Hill Road Bottomlands just south of the current study area. Only a few site visits were made during that survey: 1992-04-03, 1992-07-15, and 1994-01-25 for the Mt. Moriah Bottomlands; only on 1994-01-25 for the Game Land portion of the New Hope Bottomlands; and on 1992-04-16 and 1992-06-19 for the Old Chapel Hill Road Bottomlands. All work was done by a single investigator, Steve Hall, who also conducted the majority of the amphibian surveys in the current project.

In both the previous and current surveys, amphibians were surveyed mainly opportunistically: individuals were recorded as encountered by chance by observers walking through the sites. Concentrated log-rolling was done on a few occasions, especially in the fall and spring during periods when adult woodland salamanders are most active above ground. Eggs and larvae of some species were also searched for in their breeding pools. Frog species – as highly vocal animals – were one of the most effectively documented groups of animals in this study, along with birds and singing orthopterans.

In the current project, surveys for amphibians were spread throughout the year covered by the inventory but with a concentration during the breeding period – mainly in the spring and summer -- for chorusing frogs. Most of our efforts concentrated on the wetland habitats present in the New Hope Bottomlands. Additional records were obtained from iNaturalist/GBIF, including a few observations from the Hollow Rock Nature Park, which as a fairly dry area was not otherwise extensively surveyed for this group of species.

Summary of the Amphibian Species Recorded During the Project

A total of seventeen species of amphibians have been recorded in the study area, based on both historic and current records:

Species	Hall (1995)	iNaturalist /GBIF	New Hope Biodiversity Survey
American Bullfrog (*Lithobates catesbeianus*)		x	
American Toad (*Anaxyrus americanus*)	x	x	x
Cope's Gray Treefrog (*Hyla chrysoscelis*)	x	x	x
Eastern Narrow-mouthed Toad (*Gastrophryne carolinensis*)	x	x	x
Fowler's Toad (*Anaxyrus fowleri*)	x	x	x
Green Frog (*Lithobates clamitans*)	x		x
Green Treefrog (*Hyla cinerea*)		x	x
Southern Leopard Frog (*Lithobates sphenocephalus*)	x		x
Northern Cricket Frog (*Acris crepitans*)			x[3]
Spring Peeper (*Pseudacris crucifer*)	x		x
Upland Chorus Frog (*Pseudacris feriarum*)	x		x
Dwarf Waterdog (*Necturus punctatus*)		x	
Four-toed Salamander (*Hemidactylium scutatum*)	x		
Marbled Salamander (*Ambystoma opacum*)	x	x	x
Southern Two-lined Salamander (*Eurycea cirrigera*)		x	
Spotted Salamander (*Ambystoma maculatum*)	x	x	
White-spotted Slimy Salamander (*Plethodon cylindraceus*)	x		

Noteworthy Species

S3 SPECIES

Four-toed Salamander (*Hemidactylium scutatum*). This seep- and ephemeral pool-breeding species has been recorded at a number of sites in the New Hope watershed, including one just downstream from the study area in the Old Chapel Hill Road Bottomlands. Although surveys were conducted in the current study specifically for this species in its late winter/early spring breeding period, none were found. Similar results were obtained in an attempt by Hall and Nathan Shepard of the Natural Heritage Program to confirm the continued existence of the Four-toed Salamander population found in the Old Chapel Hill Road Bottomlands in the 1990s. Although the pools are still present where the species was previously found, no adults or egg masses were found on this trip (March 16, 2018). Debris deposited and flood-worn bark at the base of trees in the area surrounding the pools indicated that it is no longer as isolated from floodwaters as it once was.

REGIONALLY RARE SPECIES

Dwarf Waterdog (*Necturus punctatus*). This species is common in the murky, slow-moving waters of the Coastal Plain but was found decades ago in the New Hope floodplain; Joe Bailey

[3] The sole record we have for Northern Cricket Frog was made by Hall in 2020 in the New Hope Bottomlands, prior to the beginning of the current survey

and his Duke vertebrate zoology course documented this species at the Erwin Road bridge as long ago as the 1950s (J. Bailey, pers, comm. to S. Hall, 1987). Attempts to find it in the Durham County Wildlife Inventory were unsuccessful (Hall, 1995) and it was unclear whether this species managed to survive within the area following the impoundment of Jordan Lake; that project effectively cut off a population of the waterdogs in the New Hope floodplain from access to the much larger population in the Coastal Plain. However, in 2022, this species was rediscovered by Bryan Stuart, Curator of Herpetology at the NC Museum of Natural Sciences. The site -- located in Duke Forest just west of Erwin Road – was exactly where it was last documented nearly 60 years ago (Stuart, 2022). Although not yet found in the area downstream within the New Hope study area, the presence of a much larger area of suitable habitat in the New Hope Bottomlands suggests that the majority of its population may actually occur within that area.

Changes in Composition over the Past Thirty Years

The most obvious change in the amphibian fauna since the New Hope floodplain was surveyed in 1995 during the Durham County wildlife survey (Hall, 1995), is the expansion of Green Treefrogs *(Hyla cinerea*). None were recorded in this area in the previous survey but this species is now one of the most common vertebrates in the study area.

Green Treefrogs were, in fact largely unknown in this region in the 1970s, with choruses showing up in the beaver-pond wetlands at the Mason Farm Biological Reserve not until the early 1990s. Like the Carolina Anole, this species has been moving west into the Piedmont now for the past thirty years, following the restoration of beaver pond habitats that have taken place in that interval. Green Treefrogs are primarily marsh inhabitants and this is one of the species that has particularly benefited from the restoration of open, herb-rich, beaver-created wetlands in the Piedmont.

Other species, however, may not receive any benefits from the increased flooding of the New Hope Bottomlands, either from beaver activity, increased rainfall, or runoff from impervious surfaces. In addition to the Four-toed Salamander described above, no Spotted Salamanders (*Ambystoma maculatum*) were found during the current survey despite searches made in the early spring to look for egg masses or larvae of this species. Like *Hemidactylium*, this species was previously found in the Old Chapel Hill Road Bottomlands just south of the current study area. Hall (1995) also found it in the Mt. Moriah Bottomlands, where there is a recent record

for it on iNaturalist. In the area south of the Durham-Chapel Hill Boulevard, however, including the Old Chapel Road Bottomlands even further to the south, evidence for floods that sweep across the entire floodplain is easy to observe. It should be mentioned, however, that Marbled Salamanders were found in the New Hope Bottomlands area during the current survey. This species also prefers fish-free pools for breeding but appears to be somewhat more able to make use of floodplain sites than the other two species.

Also missed in the current survey but previously recorded in the Old Chapel Hill Road Bottomlands, was the White-spotted Slimy Salamander (*Plethodon cylindraceus*). This species, in contrast to the others just discussed, inhabits mesic forests on the slopes adjoining floodplains rather than the floodplains themselves; it is a much more terrestrial species, laying its eggs in burrows on land rather than in the water, hence it has no requirement for pool habitats whatsoever. No individuals of this species were found using the log-rolling search method, but slope habitats are extremely limited in the study area, with the more extensive examples located on private lands outside the limits of this project. Most of these habitats, however, have either been completely converted due to development or are in degraded condition due to increased insolation from the adjoining cleared or built-upon lands. Areas further north in the Mt. Moriah Bottomlands and Hollow Rock Nature Park were not surveyed for mesic forest salamanders, and there is at least some possibility that they may turn up in those sites.

Overall Quality of the Amphibian Community and Comparison to Similar Sites

The absence of quantitative data on amphibian populations limits our ability to make comparisons between sites, but as in the case of other taxonomic groups, we can at least compare the species list we obtained with those compiled for sites with habitats similar to those in the current survey.

The closest and most similar in terms of its location in the Triassic Basin lowlands and in the extent, age, and quality of its bottomland forests is the Mason Farm Biological Reserve. As described for the reptiles, surveys for the amphibian species present in the reserve were made in the 1970s and 80s, with the resulting species lists compiled in the Orange County natural areas inventory (Sather and Hall, 1988). A total of 23 species has been documented at this site, including 10 salamanders and 13 frogs and toads. Except possibly for the Red-backed Salamander, all of these species are expected to occur in the New Hope project area.

Another, much more intensive amphibian survey of a brownwater floodplain was conducted at the Devil's Gut TNC Preserve[4] in the 1990s (Lamb et al., 1998). Whereas the Mason Farm surveys relied mainly on opportunistic encounters, the Devil's Gut survey involved the use of cover boards, turtle traps, and PVC tubes in addition to visual encounter transects. That survey, however, documented only 19 species of amphibians. Eliminating seven species restricted to

[4] Some of this survey was done on privately owned timberlands adjoining the TNC preserve.

the Coastal Plain, only two species, the Red-spotted Newt (*Notophthalmus viridescens*) and Chamberlain's Dwarf Salamander (*Eurycea chamberlaini*), were missed in the New Hope survey but found in the Devil's Gut survey. Chamberlain's Dwarf Salamander, moreover, has not been reported in Durham County, although it is found just slightly to the east in Wake County

Of the two comparisons, the differences from the Mason Farm Reserve are the more significant. Most of those differences are among the salamanders, with five species present at Mason Farm but not found during the current or previous surveys in the Durham portion of the New Hope Creek floodplain. One of those species, the Red-backed Salamander (*Plethodon cinereus*) is a disjunct northern species in the eastern Piedmont and is confined to the vicinity of steep, north-facing slopes. While a population occurs in Duke Forest upstream in the Mud Creek drainage (discovered by Joe Bailey in the last century), it is unlikely to occur within the project area, which have mainly east- or west-facing slopes. Three other of the other missing species, Red Salamander (*Pseudotriton ruber*), Three-lined Salamander (*Eurycea guttolineata*), and Northern Dusky Salamander (*Desmognathus fuscus*), are associated with small perennial streams. All of these species could occur within the project area and will likely turn up with more survey efforts. The fifth species, Eastern Newt (*Notophthalmus viridescens*), occupies ponds and slow-moving waters and is also very likely to be present within the study area.

Of the three missing frog species, Pickerel Frog (*Lithobates palustris*) again almost certainly occurs within the project area, having been recorded upstream in the Mud Creek drainage by Hall in the Durham County wildlife survey. This is an early spring breeding species with a low-pitched song usually given underwater – it is difficult to detect at a distance and is often overlooked. The Squirrel Treefrog (*Hyla squirella*) is a primarily Coastal Plain species that is on the edge of its range in the eastern Piedmont and is still rare within this region.

The near absence of the third species, Eastern Cricket Frog (*Acris crepitans*), on the other hand, is more puzzling. This species is primarily associated with pond shorelines and other fairly open wetland edges and is abundant at Mason Farm. Its very loud clicking song is easily detected and it sings both day and night for a prolonged period beginning in the spring and continuing into early summer. The marshes under the powerline seem to be suitable habitat and one was recorded there by Hall on May 15, 2020 – preceding the current project. None, however, were heard in the current survey. More investigation is needed to confirm its status within the area and to determine whether there any factors that could account for its apparent rarity.

Conservation Concerns

The amphibians are considered to be the most endangered group of the vertebrates (Catenazzi, 2015), with up to a third of all species worldwide at risk of extinction (Wake and Vredenburg, 2008). Several causes have been identified for the declines seen in this group:

- Habitat loss: clear-cutting; livestock impacts on streams and wetlands; wetland drainage

- Highway impacts: direct traffic mortality; fragmentation of habitats even in otherwise intact areas of natural habitats
- Emergent diseases, such as chytridiomycosis and Ranavirus infection
- Pollutants, including acid deposition, sedimentation, road salt runoff
- Pesticide impacts on larvae, including herbicides such as Roundup
- Competition and predation by exotic species and expanded populations of bullfrogs and raccoons
- Climate change: prolonged droughts, increased flooding, and heat waves

Of these impacts, the first two are likely to have been particularly important for the amphibians associated primarily with mesic forests on the slopes bordering the bottomlands. These include the White-spotted Slimy Salamander, Spotted Salamander, Marbled Salamander, and Four-toed Salamander. The adults of all of these species are associated with mesic uplands, as are all life stages of the Slimy Salamander. Adult frogs and salamanders that breed in ponds move substantial distances from the breeding sites where they spend most of the year. Rittenhouse and Semlitsch (2007), for example, found that salamanders commonly move 100-200 meters from ponds, while frogs move > 500 meters. Unfortunately, much of the critical forest buffer habitat along the margins of the floodplain have been cleared, either directly for development or for the construction of large stormwater detention ponds. In addition to the direct loss of habitat, the clearing of the adjoining forests allows both sunlight and winds to penetrate much more easily into the surviving stands, which has both drying and heating impacts that are likely to affect any remaining salamander populations. The close proximity of roads and parking areas next to the floodplain is also likely to increase the heating of these stands as well as to create a new source of mortality for any amphibians that wander out of the surviving forest.

Emergent diseases, although having devastating impacts on amphibian populations around the world, do not appear to have the level of impacts in this area. Although both *Batrachochytrium dendrobatidis* (the fungus that causes chytridiomycosis) and ranavirus have been detected in Spotted Salamander populations and other species in the Southeast, they have so far not led to the mass extirpation events that have been observed elsewhere. These impacts, however, need to be closely monitored (see discussion in Watters et al. 2018).

The runoff of pollutants, pesticides, and sediments from developed areas into streams and bottomland wetlands is likely to be an increasingly important source of impacts to the amphibian populations of the study area. The use of lawn chemicals to maintain the large tracts of turf on the slopes above the bottomlands is a particular source of concern. So is the application of herbicides to suppress vegetation growing under the powerline. Herbicides such as Roundup have been shown to have significant impacts on larval amphibians (see Relyea, 2005, 2011). While other herbicides such as Arsenal have not yet been shown to have the same level of impacts, only a few species of amphibians – mainly Bullfrogs -- have actually been tested for the effects of imazapyr, the active ingredient in Arsenal. If smaller species, such as

Eastern Cricket Frogs, are susceptible, their apparent absence from the marshes under the powerline may be due to that cause.

With the possible exception of coyotes, no introduced species that affect amphibian populations have been detected in the New Hope project area. However, one of the expected effects of climate change is to facilitate the invasion of warm-climate species into our area, including Nine-banded Armadillos, which prey on a wide range of small, ground-dwelling vertebrates. Monitoring will be needed to detect the arrival of such species and to track any changes in the amphibian populations that may result.

One impact of climate change that may already be having an impact is the increased frequency and severity of flooding. While inundation of the bottomlands may have little direct impact on frogs and aquatic salamanders, the introduction of fish into nearly all parts of the floodplain greatly reduces the availability of suitable breeding sites. The eggs and larvae of many species of frogs and salamanders are preyed upon by even small species of fish such as Eastern Mosquitofish (*Gambusia holbrooki*), which can be seen in most of the large floodplain pools that occur across the floodplain. Species such as Spotted Salamander, Marbled Salamander, Four-toed Salamander, Upland Chorus Frog, and Spring Peeper may all be losing breeding habitat due to this cause. Conversely, the species that appear to be doing well in the New Hope Bottomlands, particularly Green Treefrog and the species of Lithobates, all have larvae that are well-adapted to the presence of fish.

One additional potential impact to amphibian populations in the New Hope Bottomlands is the great reduction that appears to have taken place in the macro-moth fauna. Like the breeding birds that may have declined in this area due to the reduction of their major prey, the loss of adult moths as well as caterpillars can be expected to have an impact particularly on frog species. That both Green Treefrogs and Cope's Gray Treefrogs still seem to have vigorous populations in the New Hope Bottomlands appears to contradict that hypothesis. However, quantitative data will be needed in order to determine whether there are any reductions in the number of individuals taking place that are correlated with the reductions of their prey species.

Conservation Recommendations

1. Reduce habitat fragmentation and edge effects. Protect more land as buffers for the existing tracts in conservation management. Allow buffers of native trees and shrubs to develop in areas where they have been cleared in between residential areas and businesses and the preserves. Protect any areas that can increase the amount of land in conservation, particularly tracts that are contiguous with existing protected lands or that serve to connect them. Find alternative routes for new roads, powerlines, sewer lines, and other infrastructure that avoid the conservation lands.
2. Reduce stormwater runoff from adjoining developed areas. Use permeable surfaces for parking areas. Plant only native species in stormwater detention ponds. Find alternatives to the use of herbicides to maintain vegetation used for landscaping

3. Carefully site trails in order to prevent disturbance of nesting habitats. Prohibit the use of off-road vehicles in preserves.
4. Continue to monitor amphibian populations, ideally conducting them at the same time as surveys for moths and other insects. Any individuals that appear to be diseased need to be collected for laboratory examination.

References

Catenazzi, A., 2015. State of the world's amphibians. Annual Review of Environment and Resources, 40(1):91-119. Available online at: https://www.annualreviews.org/doi/pdf/10.1146/annurev-environ-102014-021358

Jolley, D.B., Ditchkoff, S.S., Sparklin, B.D., Hanson, L.B., Mitchell, M.S. and Grand, J.B., 2010. Estimate of herpetofauna depredation by a population of wild pigs. Journal of Mammalogy, 91(2):519-524. Available online at: https://academic.oup.com/jmammal/article/91/2/519/902506

Lamb, T., Gaul Jr, R.W., Tripp, M.L., Horton, J.M. And Grant, B.W., 1998. A herpetofaunal inventory of the lower Roanoke River floodplain. Journal of the Elisha Mitchell Scientific Society 114:43-55. Available online at: https://www.science.widener.edu/~grant/projects/pubs/Lambetal1998.pdf

Relyea, R.A. 2005. The impact of insecticides and herbicides on the biodiversity and productivity of aquatic communities. Ecological Applications 15:618-627

Relyea, R.A., 2011. Amphibians are not ready for Roundup®. In Wildlife ecotoxicology (pp. 267-300). Springer, New York, NY. Available online at: https://www.biology.pitt.edu/sites/default/files/facilities-images/Relyea_pubs/2011%20Relyea%20chapter.pdf

Rittenhouse, T.A.G. and R.D. Semlitsch. 2007. Distribution of amphibians in terrestrial habitat surrounding wetlands. Wetlands 27:153-161.

Stuart, B. 2022. Gills on a Puppy Dog's Face in the Duke Forest. NCMNS News. Available online at: https://naturalsciences.org/calendar/news/gills-on-a-puppy-dogs-face-in-the-duke-forest/

Sutherland, R.W., 2009. The effects of urbanization on reptiles and amphibians in the Sandhills region of North Carolina. Doctoral dissertation, Duke University. Available online at: https://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/3199/MicrosoftWord-RonaldSutherlandDissertationFinalDraft20096_1_09.pdf?sequence=1&sa=U&ei=D2RhU-KFBMO32wWstIHACA&ved=0CDEQFjAF&usg=AFQjCNHTAlXhLx-U05XZ0lIxXdio_9cNAg

Wake, D.B. and Vredenburg, V.T., 2008. Are we in the midst of the sixth mass extinction? A view from the world of amphibians. Proceedings of the National Academy of Sciences, 105(supplement_1):11466-11473. Available online at: https://www.pnas.org/doi/pdf/10.1073/pnas.0801921105

Watters, J.L., Davis, D.R., Yuri, T. and Siler, C.D., 2018. Concurrent infection of Batrachochytrium dendrobatidis and ranavirus among native amphibians from northeastern Oklahoma, USA. Journal of Aquatic Animal Health, 30(4):291-301. Available online at: https://www.researchgate.net/profile/Jessa-Watters/publication/328122127_Concurrent_Infection_of_Batrachochytrium_dendrobatidis_and_Ranavirus_among_Native_Amphibians_from_Northeastern_Oklahoma_USA/links/5bbb57184585159e8d8c3589/Concurrent-Infection-of-Batrachochytrium-dendrobatidis-and-Ranavirus-among-Native-Amphibians-from-Northeastern-Oklahoma-USA.pdf

Reptiles

Biology and Characteristics

Reptiles are no longer what they once were. With the recognition of the close relationship between birds and dinosaurs, the definition of what traits identify reptiles as a distinct group is undergoing new scrutiny, with no clear consensus yet emerging about whether to retain all of the previous members or split some of them out into separate classes. In this section, we deal with lizards and snakes (members of the Squamata), which still fit the old definition – species that lay amniotic eggs, have scaly integuments, and are poikilothermic (with body temperatures determined by the environment). We also include turtles, which also still fit the older definition, although they actually appear to be more closely related to dinosaurs and birds than to the Squamata.

Among the Tetrapods (primarily terrestrial, four-legged vertebrates), modern reptiles are second behind birds in number of species worldwide. However, most reptiles live in the tropics or subtropics and this group is much less diverse in North Carolina than the other groups; 75 native or established species of reptiles occur here compared to 94 amphibians, 124 mammals and 494 birds. 41 species have been recorded within Durham and Orange Counties, including 8 turtles, 12 lizards (three introduced, one now probably extirpated), and 22 snakes.

Compared to amphibians, reptiles are much less tied to water in all of their life. The majority lay eggs on dry land with a few ovoviviparous species retaining their eggs within the female's oviduct, where they hatch, giving birth to live young. These key adaptations allow our species to be fully terrestrial and, unlike even the most terrestrial of the amphibians, they can be diurnally active in even the driest and hottest of our habitats. At the other extreme, a few species, including most turtles and some watersnakes, are aquatic or semi-aquatic. Although more limited than birds or mammals by cold climates, reptiles occupy nearly the entire range of terrestrial and freshwater habitats in North Carolina, with a few even adapted to the saline conditions of our coastal marshes and sounds or, in the case of sea turtles, deep sea environments.

In all of these habitats, reptiles play important roles within the food web of their ecosystems. Most are secondary consumers, feeding on other animals, although some turtles and lizards are omnivorous, feeding on both plants and animals. Insects are the prey of most lizards and the Rough Greensnake. Arthropods more generally, along with earthworms and gastropods, are important foods for several small, semi-fossorial snakes, while larger snakes feed mainly on vertebrates, including fish, amphibians, other reptiles, small mammals, and birds. Reptiles, in turn, form an important part of the prey base of predatory mammals and birds.

Survey Efforts

Reptiles were previously surveyed in the study area as part of the Durham County wildlife survey (Hall, 1995) but that work was done mainly in the Mt. Moriah Bottomlands and the Old Chapel Hill Road Bottomlands just south of the current study area. Only a few site visits were made during that survey: 1992-04-03, 1992-07-15, and 1994-01-25 for the Mt. Moriah Bottomlands; only on 1994-01-25 for the Game Land portion of the New Hope Bottomlands; and on 1992-04-16 and 1992-06-19 for the Old Chapel Hill Road Bottomlands. All work was done by a single investigator, Steve Hall, who also conducted the majority of the reptile surveys in the current project.

In both the previous and current surveys, reptiles were surveyed opportunistically, recorded as encountered while an observer walked through the sites. Log-rolling was done throughout the year but was done on a more concentrated basis on a few occasions, especially in the fall and spring.

Survey efforts for this group in the current project were concentrated in the New Hope Bottomlands and were conducted mainly by Steve Hall. Additional records were obtained from iNaturalist, including a number of observations from the Hollow Rock Nature Park.

Summary of the Reptile Species Recorded During the Project

A total of twelve species of reptiles have been recorded in the study area, based on both historic and current records, but only eight were observed in this survey itself, with only a single species added to the list for study area:

Scientific Name	Hall (1995)	New Hope Creek Survey	iNaturalist/ GBIF
Turtles			
Snapping Turtle (*Chelydra serpentina*)	x		
River Cooter (*Pseudemys concinna*)		x	x
Eastern Musk Turtle (*Sternotherus odoratus*)	x		
Eastern Box Turtle (*Terrapene carolina*)	x	x	
Pond Slider (*Trachemys scripta*)		x	
Lizards			
Carolina Anole (*Anolis carolinensis*)		x	
Five-line Skink (*Plestiodon fasciatus*)		x	
Fence Lizard (*Sceloporus undulatus*)			x
Snakes			
Copperhead (*Agkistrodon contortrix*)			x
North America Racer (*Coluber constrictor*)	x		
Ring-necked Snake (*Diadophis punctatus*)			x
Plain-bellied Watersnake (*Nerodia erythrogaster*)		x	x
Northern Watersnake (*Nerodia sipedon*)			x
Rough Greensnake (*Opheodrys aestivus*)			x

Scientific Name	Hall (1995)	New Hope Creek Survey	iNaturalist/ GBIF
Eastern Ratsnake (*Pantherophis alleghaniensis*)		**x**	**x**
Dekay's Brownsnake (*Storeria dekayi*)		**x**	**x**
Red-bellied Snake (*Storeria occipitomaculata*)			**x**

Noteworthy Species

All species that have been recorded in the study area are common and widespread in North Carolina. No species designated as Significantly Rare by the Natural Heritage Program are likely to occur within this area, although both Timber Rattlesnake (*Crotalus horridus*) and Slender Glass Lizard (*Ophisaurus attenuatus*) may once have had populations within this vicinity (both species still occur in the northern part of Durham County).

The population of one species in the study area, the Pond Slider, appears to be a hybrid between the native Pond Slider (*Trachemys scripta scripta*) and the non-native subspecies, the Red-eared Slider (*T. s. elegans*); individuals with both red and yellow post-ocular patches have been observed in the New Hope Bottomlands.

Changes in Composition over the Past Thirty Years

Three species were recorded in the 1990s but not seen in recent surveys: Snapping Turtle (*Chelydra serpentina*), Eastern Musk Turtle (*Sternotherus odoratus*), and North American Racer (*Coluber constrictor*). The two turtles are highly aquatic and are easily overlooked; both species are likely to still occur within the study area. The racer, on the other hand, is one of the more conspicuous species of snakes, being highly active during the day. While we suspect that it is still present in the area, the lack of observations during the current survey indicate that it may have become much less common now than it was formerly.

One other species that was missed in the earlier survey but is now very common is the Carolina Anole (*Anolis carolinensis*). This species was seen only occasionally in this part of the Piedmont in the 1970s and 1980s (Hall, pers. obs.) but has been increasing in numbers and distribution since that time and is probably now the most frequently observed reptile in our area. This increase has likely resulted from the warming of temperatures throughout the year and especially from the reduction in extreme cold snaps during the winter.

Overall Quality of the Reptile Community and Comparison to Similar Sites

We have no quantitative data from either the current survey or from past surveys in similar habitats in North Carolina on which to base comparisons. However, both the diversity and abundance of the reptile fauna in the New Hope floodplain appear to be much lower than what we would expect based on qualitative surveys conducted by the Natural Heritage Program in several brownwater floodplains in the past.

The most intensively surveyed of these areas, as well as the one closest in proximity and habitat composition to the New Hope study area, is the Mason Farm Biological Reserve. Based on a number of field projects conducted by the UNC zoology students and faculty, a total of 25 species were recorded at Mason Farm in the 1970s and 80s (see list compiled by Sather and Hall, 1988). These include six species of turtles, fourteen species of snakes, and five species of lizards. 22 species (including three restricted to the Coastal Plain) were also recorded in an intensive survey of the Devil's Gut TNC Preserve[5] in the 1990s (Lamb et al., 1998). Whereas the Mason Farm surveys relied mainly on opportunistic encounters, the Devil's Gut survey, was much more intensive, involving the use of cover boards, turtle traps, and PVC tubes in addition to visual encounter transects.

Among the species missing from the current survey but documented frequently at Mason Farm and Devil's Gut was the Ground Skink (*Scincella lateralis*), one of the most abundant species of reptile in the state. Although a fairly inconspicuous member of the leaf-litter fauna, it is usually easy to detect the rustling sound it makes as it scurries through the leaves. It was commonly observed not only at Mason Farm and Devil's Gut, but also in the following brownwater floodplain sites surveyed between 1990 and 2015 by the Natural Heritage Program: Upper Roanoke River Wetlands Game Land (LeGrand and Hall, 2014); Roanoke Big Oak Woods TNC Preserve (LeGrand and Hall, 2014); and Tar River Floodplain survey, three sites (Hall, unpublished field notes, 2013).

Other larger and diurnally-active species that were missed in the current survey include Broad-headed Skink (*Plestiodon laticeps*), Eastern Hognose Snake (*Heterodon platirhinos*), Eastern Kingsnake (*Lampropeltis getula*), and Common Garter Snake (*Thamnophis sirtalis*). More cryptic but easily found by rolling logs is the Common Worm Snake (*Carphophis amoenus*). Even the large, diurnal species that were recorded in the study area, including Eastern Rat Snake and American Racers, appeared to be far less commonly encountered than they were in the sites and years listed above. At Mason Farm in the 1970s-80s, one or more of these species would be seen on any given day (Hall, pers. obs.). In the current survey, no racers were seen at all and only a few ratsnakes and watersnakes.

Conservation Concerns

Without quantitative data, the apparent reduction in diversity and abundance of reptile species in the New Hope floodplain needs much more confirmation. As was true for the macro-moths and Neotropical migrant birds, however, this pattern of reduction is similar to what has been observed more widely (see Todd et al., 2010, for a global review).

These reductions have frequently been described as "enigmatic," referring to the decline of species even in protected areas for reasons that are still obscure (e.g., Winne et al., 2007). As with the insect declines, there appear to be a number of possible causes. These include:

[5] Some of this survey was done on privately owned timberlands adjoining the TNC preserve.

- Predation by invasive species, including Red Imported Fire Ants (Swarthout and Willson, 2022), Nine-banded Armadillos (Fitch et al., 1952), or feral hogs (Jolley et al., 2010)
- Emergent diseases, such as Snake Fungal Disease (Lorch et al., 2016)
- Road impacts and the effects of urbanization more generally with regard to habitat loss, degradation, and fragmentation (Sutherland, 2009; Godley et al., 2017)
- Climate change, including impacts of more severe floods and droughts (Winne et al., 2007)

Of these causes, nest predation by fire ants appears to be unlikely within the New Hope study area. Although this species occurs in the vicinity – a fairly high density of fire ant nests occurs along the undeveloped right-of-way on the slope above the bridge on US 15-501 – they appear to be largely absent from the forests both in the bottomlands and in the upland areas of the Hollow Rock Nature Park. Armadillos and feral hogs have also yet to reach this part of the state. Coyotes, however, are now common in the study area and are known to prey on large snakes. They have also been increasing at about the same time that the reptiles in this area appear to have been declining and are likely to be having at least some impact.

Roads and urbanization are also highly likely to be the source of some of these declines. The great increase in development and traffic along the Durham-Chapel Hill Boulevard as well as the construction of residential areas along the very edges of the floodplain on both sides of the New Hope Bottomlands is certain to have created an increase in mortality for many reptile species. The loss of woodlands and rural lands in the uplands adjoining the New Hope floodplain not only has reduced the overall habitat available for many of the species that also make use of the bottomlands, but these habitats have been replaced by habitat sinks – areas that species may stray into but where they cannot survive, let alone reproduce. Box Turtles that are occasionally found in residential neighborhoods almost always represent individuals that no longer contribute reproductively to their original population, whether or not they can continue to survive as individuals within small remnants of their former habitat. More often than not, the high mortality rates of reptile species in developed areas cuts even that possibility short. Increased human recreational use of the bottomlands probably also creates some additional mortality among at least the larger snakes and the removal as pets of species such as Box Turtles.

Those factors, however, are less likely to explain the loss of Ground Skinks or small, secretive snake species. Apart from sampling issues, two possibilities appear to exist for these species. First, they may be periodically decimated by the floods that are now increasing in frequency and/or severity in the New Hope floodplain. Lamb et al (1998) noted that the lower parts of the floodplain in the Devil's Gut study area contained significantly fewer reptile species than those on the drier floodplain ridges. They further speculated that the artificial changes in the flood regime in that resulted from constructing several large reservoirs upstream may have altered the overall composition and distribution of its herpetofauna within the entire floodplain.

Second, the leaf-litter insect fauna – the primary prey base of the Ground Skink – may have undergone a severe decline in the New Hope Bottomlands (see Macro-moth summary). At both Mason Farm and at Devil's Gut, where extensive surveys were conducted of the macro-moths during the same time periods that the reptiles were inventoried, no such deficit was observed. While there is some possibility that increased flooding may be affecting the litter-dwelling moths in the New Hope floodplain, other groups that are less likely to be affected by flooding show the same pattern of deficits, indicating that other factors are probably involved. In any case, one or both of these two factors could possibly explain a decrease in the abundance of Ground Skinks in the study area.

More intensive and systematic surveys of the reptile fauna of the New Hope floodplain will need to be done in order to confirm that there are, in fact, any reductions in diversity or abundance among members of this particular group. Special attention needs to be given to comparing areas of the floodplain that are regularly flooded and the less frequently flooded slopes that adjoin the floodplain, as well as the small number of ridges located out in the floodplain itself (several were found during the survey although none as extensive as those at Devil's Gut).

Conservation Recommendations

1. Reduce habitat fragmentation and edge effects. Protect more land as buffers for the existing tracts in conservation management. Allow buffers of native trees and shrubs to develop in areas where they have been cleared in between residential areas and businesses and the preserves. Protect any areas that increase the amount of land in conservation, particularly tracts that are contiguous with existing protected lands or that serve to connect them. Find alternative routes for new roads, powerlines, sewer lines, and other infrastructure that avoid the conservation lands.
2. Maintain or restore natural vegetation. Eradicate exotic invasives that provide little, if any, food for native insects and replace them with native species, particularly those that are rich in terms of native insect herbivores. In the bottomland forests, restore the natural, multi-layered structure. In the powerline, enhance natural habitats by allowing marshes or beaver ponds to develop in open wetland areas. Allow shrubs and trees to grow within herbicide-free patches may also allow species associated with successional or edge habitats to occupy the area.
3. Reduce stormwater runoff from adjoining developed areas. Use permeable surfaces for parking areas. Plant only native species in stormwater detention ponds.
4. Carefully site trails in order to prevent disturbance of nesting habitats. Prohibit the use of off-road vehicles in preserves.
5. Continue to monitor reptile populations, ideally conducting them at the same time as surveys for moths and other insects. Any individuals that appear to be diseased need to be collected for laboratory examination.

References

Fitch, H. S., P. Goodrum & C. Newman. 1952. The armadillo in the southeastern United States. Journal of Mammalogy 33: 21–37

Hall, S.P. 1995. Inventory of the Wildlife Habitats, Movement Corridors, and Rare Animal Populations of Durham County, North Carolina. Unpubl. Report to Durham Inventory Review Committee and Triangle Land Conservancy; NC Natural Heritage Program. Available online at: https://digital.ncdcr.gov/digital/collection/p249901coll22/id/184104

Godley, J.S., Halstead, B.J. and McDiarmid, R.W., 2017. Ecology of the Eastern Kingsnake (Lampropeltis getula) at Rainey Slough, Florida: a vanished eden. Herpetological Monographs, 31(1):47-68. Available online at: https://www.researchgate.net/profile/Steve-Godley/publication/318038775_Ecology_of_the_Eastern_Kingsnake_Lampropeltis_getula_at_Rainey_Slough_Florida_A_Vanished_Eden/links/59513e600f7e9b329234c6f2/Ecology-of-the-Eastern-Kingsnake-Lampropeltis-getula-at-Rainey-Slough-Florida-A-Vanished-Eden.pdf

Jolley, D.B., Ditchkoff, S.S., Sparklin, B.D., Hanson, L.B., Mitchell, M.S. and Grand, J.B., 2010. Estimate of herpetofauna depredation by a population of wild pigs. Journal of Mammalogy, 91(2):519-524. Available online at: https://academic.oup.com/jmammal/article/91/2/519/902506

Lamb, T., Gaul Jr, R.W., Tripp, M.L., Horton, J.M. And Grant, B.W., 1998. A herpetofaunal inventory of the lower Roanoke River floodplain. Journal of the Elisha Mitchell Scientific Society 114:43-55. Available online at: https://www.science.widener.edu/~grant/projects/pubs/Lambetal1998.pdf

LeGrand, H.E. Jr. and Hall, S.P. 2014. A Natural Heritage Inventory of the Roanoke River Floodplain, North Carolina. North Carolina Natural Heritage Program. Available online at: https://apnep.nc.gov/media/286/open

Lorch, J.M., Knowles, S., Lankton, J.S., Michell, K., Edwards, J.L., Kapfer, J.M., Staffen, R.A., Wild, E.R., Schmidt, K.Z., Ballmann, A.E. and Blodgett, D., 2016. Snake fungal disease: an emerging threat to wild snakes. Philosophical Transactions of the Royal Society B: Biological Sciences, 371(1709), p.20150457. Available online at: https://royalsocietypublishing.org/doi/full/10.1098/rstb.2015.0457

Sutherland, R.W., 2009. The effects of urbanization on reptiles and amphibians in the Sandhills region of North Carolina. Doctoral dissertation, Duke University. Available online at: https://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/3199/MicrosoftWord-RonaldSutherlandDissertationFinalDraft20096_1_09.pdf?sequence=1&sa=U&ei=D2RhU-KFBMO32wWstIHACA&ved=0CDEQFjAF&usg=AFQjCNHTAlXhLx-U05XZ0llxXdio_9cNAg

Swartwout, M.C. and Willson, J.D., 2022. Southeastern US Snake Species are Vulnerable to Egg Predation by Red Imported Fire Ants (*Solenopsis invicta*). Herpetologica, 78(2), pp.139-144.

Todd, B.D., Willson, J.D. and Gibbons, J.W., 2010. The global status of reptiles and causes of their decline. Ecotoxicology of amphibians and reptiles, p 47-67. In: Sparling, Bishop, and Krest (eds.) Ecotoxiclology of Amphibians and Reptiles, Second Edition. CRC Press, Pensacola. Available online at: https://www.researchgate.net/profile/Brian-Todd-2/publication/278304526_The_Global_Status_of_Reptiles_and_Causes_of_Their_Decline/links/5633c6de08ae758841121b13/The-Global-Status-of-Reptiles-and-Causes-of-Their-Decline.pdf

Winne, C.T., Willson, J.D., Todd, B.D., Andrews, K.M. and Gibbons, J.W., 2007. Enigmatic decline of a protected population of eastern kingsnakes, *Lampropeltis getula*, in South Carolina. Copeia, 2007(3), pp.507-519. Available online at: https://www.researchgate.net/profile/Christopher-Winne/publication/254948138_Enigmatic_Decline_of_a_Protected_Population_of_Eastern_Kingsnakes_Lampropeltis_Getula_in_South_Carolina/links/00b49530e813d5fa8f000000/Enigmatic-Decline-of-a-Protected-Population-of-Eastern-Kingsnakes-Lampropeltis-Getula-in-South-Carolina.pdf

Birds

Biology and Characteristics

Birds are the most diverse group of terrestrial Vertebrates. Apart from a few nocturnal species, birds are diurnally active, with conspicuous visual and vocal displays. Those behaviors – plus their ability to fly -- make them among the best-known groups of organisms to humans. As such, they have received a great deal of study, both from biologists and birders. This is evident in the amount of information available in the summary given below.

Ecologically, birds are mainly secondary consumers, preying on other consumers, especially insects. As such, the integrity of the bird community is strongly dependent on the integrity of both the plant and insect communities. In the case of the group of species that migrate south in the winter and return to breed in our area in the summer, these species are especially dependent on the caterpillars of moths and butterflies, a factor that closely ties the fates of these two taxa together.

In the analysis that follows, we divide birds into four categories based on their residential status at different times of the year. Permanent Residents are those that are found in the study area throughout the year. Winter Residents are resident solely as non-breeding species, occurring from late summer to early spring. Summer Residents are present during the nesting season but migrate out of the area – usually well to the south – in the fall and return in the late spring. Finally, Migrants are only transiently present as they pass through our area to nesting sites further to the north or to wintering areas in the south. Another category – Visitors – can also be defined as species that nest or winter in the vicinity but depend on habitats other than those in the study area and are only occasionally found within the study area. Consequently, they provide less information about habitat quality than the other four categories and are largely left out of our evaluation of the study area.

Nomenclature, both common and scientific names, follows the latest American Ornithologists' Union Checklist and supplements, as adopted by the Birds of North Carolina Website (http://ncbirds.carolinabirdclub.org/). In cases where a species nests in one area of North Carolina but is either a migrant or wintering species in the New Hope Project area, we append a descriptor to indicate its non-breeding status (e.g., *Junco hyemalis*, winter).

Survey Efforts

Surveys were conducted by walking through the sites and recording all species either seen or heard singing; in some cases, records were also made on the basis of tracks or feathers. All but one survey visits were made during the day, with some nocturnal species probably missed as a result.

NEW HOPE BOTTOMLANDS: Most of this tract was in private ownership at the time of the Durham County Wildlife Inventory (Hall, 1995). Only the Corps-owned land at the southern end

of this tract was visited during that survey and the only trip was made during late January. However, the tract of bottomlands just south of Old Chapel Hill Road was visited three times during that survey, including twice in April and once in June, with bird lists made on all three visits. During the current inventory, birds were recorded on 34 different dates by various members of the NCBP. Bird-focused surveys (with more than 15 records) were done in 2022 by Harry LeGrand, Lori Arent, Claire Sullivan, Steve Hall, and Carol Tingley on March 13; by Harry LeGrand, Steve Hall, Ed Harrison on April 22; and by Hall on March 14, March 18, April 5, April 13, April 22, May 2, May 3, May 6, May 16, May 23, June 6, June 28, and July 1. Additionally, 181 records were extracted from eBIRD, including 33 records that were made as part of New Hope Audubon's Christmas Bird Count and 38 records made on May 7, 2022 by Bo Howes (eBIRD, accessed 2022-10-12).

HOLLOW ROCK NATURE PARK: This tract was not surveyed during the Durham County Wildlife Inventory but visits were made to this site by Steve Hall during site evaluations made by NHP for the Ecosystem Enhancement Program. Bird counts were done during field visits to what was then the Penny Tract on April 12, 21, and 22 in 2005. During the current survey, bird counts were made in 2022 by Steve Hall and Van Cotter on February 14 and by Harry LeGrand, Steve Hall, Lori Arent, Claire Sullivan, and Carol Tingley on March 18. This site is regularly visited by birders and 546 records were extracted from eBIRD for this site, from the period 2021-08-09 to 2022-08-07. These include 150 records from May and June, 2022, the primary months for nesting. These include 21 species recorded on a breeding bird survey made by the New Hope Audubon Society on June 29.

MT. MORIAH BOTTOMLANDS: The floodplain just north of US 15-501 was visited during the Durham County Wildlife inventory on April 3 and July 25 in 1992 and on January 25, 1994. In the current survey, bird counts were made in 2022 by Steve Hall along the lower portions of both the Mud Creek and New Hope Creek floodplains on June 6 and again on July 19.

MUD CREEK BOTTOMLANDS: Although portions of the Mud Creek floodplain that are included within the Durham Division of Duke Forest were visited during the Durham County Wildlife Inventory, the habitats in those areas – including an artificially created Cypress swamp – are substantially different from those found in the tract of County-owned land that we identify as the Mud Creek Bottomlands. Consequently, we do not include the bird records from those areas in this analysis. Although bird surveys were not done at this site during the course of the current inventory, we expect its fauna to be similar to that recorded in the lower part of the Mud Creek floodplain, where bird counts were done by Steve Hall on June 6 and July 19, 2022.

Summary of the Bird Species Recorded During the Project

107 species have been recorded in the survey area, based on the record sources described above; 85 of which were documented during the New Hope Survey. The complete list is given in Appendix 14 and includes 50 permanent residents, 16 winter residents, 32 summer residents, and 9 migrants/transients.

Noteworthy Species

Only a few species of birds found in the Piedmont are currently considered to be of significant conservation concern by the Natural Heritage Program. The following are included either on the Program's Rare List or Watch List (Ratcliffe, 2020):

S2 SPECIES

Yellow-crowned Night Heron (*Nyctanassa violacea*). This elegant crayfish-feeding species was observed at one of the woodland pools within the New Hope Bottomlands on May 6, 2022 by Steve Hall and with a second record from this same spot posted on iNaturalist from June 30, 2022 ("Gibbous", iNaturalist, accessed 2022-10-11). This species is strongly associated with swamp forests and has most of its North Carolina populations in the Coastal Plain. Although it has been considered to be quite rare as a nesting species in the Piedmont (LeGrand et al., 2022), a breeding population appears to have existed for some time in the extensive tracts of bottomland forests in the Durham Triassic Basin (parents with young were observed by S. Hall at the Mason Farm Preserve in the 1980s). Although we only know of the two records within the New Hope Bottomlands itself, iNaturalist and eBird both have a number of records from nearby sites, with clusters of observation from Sandy Creek Park, located on a nearby tributary of New Hope Creek, and at a stormwater detention pond at the south end of the Patterson Place shopping center, located less than 0.5 miles from where the observations were made in the New Hope Bottomlands. Young birds have been photographed at that site (see below), strongly indicating that this species nests somewhere within the vicinity.

S3 SPECIES

Bald Eagle (*Haliaeetus leucocephalus*). This species was once famously on the Endangered Species List but has strongly recovered from its past declines – largely due to DDT poisoning – and is now considered secure at the National Level. In North Carolina, however, it is still listed as a Threatened Species. It was observed on two occasions during the survey but only as a transient, possibly using the New Hope corridor as a connector between Jordan Lake, where it has had a resident population since at least the 1980s, and the Eno River.

Rusty Blackbird (*Euphagus carolinus*). This species has undergone a precipitous decline for unknown reasons but is currently placed only on the Watch List by the NC Natural Heritage Program. In our area, Rusty Blackbirds are present only during the winter, with nesting taking place in the boreal forests of Canada and a few sites in extreme northern US. During its winter

stay, it is strongly associated with swamp forests and wet hardwoods and is a regular visitor to the New Hope Bottomlands. During the study period, sightings were made in December, 2021 (Howes, eBIRD, accessed 2022-10-11).

S1B/S4N SPECIES

Hooded Merganser (*Lophodytes cucullatus*). This is another species associated with swamp forests, nesting in tree cavities located in or near small forest ponds. While it is considered to be quite rare as a nesting species in North Carolina (it is placed on the Watch List by NHP), it is fairly regular but uncommon wintering bird, again preferring forest habitats with small ponds. During the survey, a pair was observed on January 5, 2022, by Steve Hall and John Petranka at a beaver pond at the Hollow Rock Nature Park. As with the Yellow-crowned Night Heron, there are a number of records for this species from both the Sandy Creek Park and the stormwater detention pond at Patterson Place. Although there is at least one record from as late in the season as May 9th, there is no evidence that this species nests within the study area. As with the Rusty Blackbird, we regard it solely as a winter resident.

Several other habitat specialists were recorded during the project and are discussed under the Habitat Analysis portion of this report.

Overall Quality of the Avian Community; Comparison to Similar Sites

The most comparable site to the current project area for which substantial bird records have been compiled is the University of North Carolina's Mason Farm Biological Reserve in Orange

County. Like the area surveyed in the current project, the Big Oak Woods is a stand of mature hardwoods located in the broad floodplain of the Triassic Basin portion of Morgan Creek; before impounding of Jordan Lake, the Morgan Creek and New Hope Creek were confluent, forming the upper end of the former New Hope River. In addition to the mature tract of bottomland hardwoods found in the reserve's Big Oak Woods, an area of uplands on the western edge of the reserve is similar in composition to the uplands found at the Hollow Rock Nature Park. In both cases, records for bird species extend back over the past several decades.

Based on the eBIRD species list for Mason Farm and considering only those associated with forested habitats, none were recorded in the project area but not at Mason Farm, consistent with the general similarity of the two areas in terms of their habitats. While there could be important differences in population sizes and densities between the two areas, quantitative data are missing from the project area (although there is a wealth of such data for Mason Farm).

On the other hand, 17 species have been recorded at Mason Farm but not in the New Hope project area. All of these missing species, however, are either migrants or species that nest in North Carolina outside of the eastern Piedmont (e.g., Mississippi Kite). The fact that they have been observed at Mason Farm but not along New Hope Creek is likely due to the much longer time period that records have been compiled at Mason Farm – 1961 is the earliest date for entries on eBIRD for that site – as well as the much greater number of observers.

Overall, these results indicate that the bird fauna of the New Hope project area has been typical of the region, at least qualitatively, over the past several decades. However, momentous changes have occurred in bird populations across all of North America over the past thirty years, as is discussed below.

Changes in Composition over the Past Thirty Years

In a recent paper, Rosenberg et al. (2019) estimated that bird populations had declined by 29% across North America, representing the loss of approximately 3 billion individuals since 1970. The authors identified a number of causes for this massive decline, one of which – the decline in numbers and diversity of insects, the main food of the majority of birds – will be discussed in another section of this report.

Locally, Haven Wiley (pers. comm. to S. Hall) has noted the decline or outright loss of a number of bird species at Mason Farm, all of which had been regular nesting species back in the 1970s through early 1990s, when intensive breeding bird counts were made there on an annual basis. Although we do not have the same level of detailed information as in the Mason Farm studies, major changes in the bird fauna within the New Hope Creek floodplain and adjoining slopes can be seen by comparing the bird lists compiled in the early 1990s and 2000s (Hall, 1995, 2005)

and the results of the current study[6]. In the earlier surveys, bird lists were compiled on only a few dates and breeding status is estimated based on the observation of the species in the second half of June, well past the end of the migratory period. We use the same criterion for the current data but also made use of the number of overall dates of observation during the nesting period to determine residency status.

The following table presents the results of the breeding bird surveys, with only those species shown that were recorded as nesting species in the surveys conducted from 1992-2005 (for a full list of the bird species recorded in the project area, see Appendix 14). Species are distinguished based on their residency status: P = Permanent Resident, S = Summer Resident. The Comments column indicates the seasons when the species was observed: the two time periods are separated by a "/ "and the seasons by W = winter, S = spring, B = breeding period, and F = fall.

Breeding Birds				
Species	**Residency Status**	**1992-2005**	**2021-2022**	**Comments**
American Goldfinch (*Spinus tristis*)	P	+	+	SB/WSBF
American Woodcock (*Scolopax minor*)	P	+		WB/-
Blue Jay (*Cyanocitta cristata*)	P	+	+	WSB/WSBF
Brown-headed Cowbird (*Molothrus ater*)	P	+	+	B/SB
Carolina Chickadee (*Poecile carolinensis*)	P	+	+	WSB/WSBF
Carolina Wren (*Thryothorus ludovicianus*)	P	+	+	SB/WSBF
Common Grackle (*Quiscalus quiscula)*	P	+	+	B/WSBF
Downy Woodpecker (*Dryobates pubescens*)	P	+	+	WSB/WSBF
Great Horned Owl (*Bubo virginianus*)	P	+	+	B/W
Hairy Woodpecker (*Dryobates villosus*)	P	+	+	WSB/WSBF
Northern Cardinal (*Cardinalis cardinalis*)	P	+	+	WSB/WSBF
Pine Warbler (*Setophaga pinus*)	P	+	+	SB/WSBF
Red-bellied Woodpecker (*Melanerpes carolinus*)	P	+	+	WSB/WSBF
Red-shouldered Hawk (*Buteo lineatus*)	P	+	+	WSB/WSBF
Tufted Titmouse (*Baeolophus bicolor*)	P	+	+	WSB/WSBF
White-breasted Nuthatch (*Sitta carolinensis*)	P	+	+	WSB/WSBF
Wild Turkey (*Meleagris gallopavo*)	P	+	+	S/WSF (probably resident)
Acadian Flycatcher (*Empidonax virescens*)	S	+	+	SB/SB
Blue-gray Gnatcatcher (*Polioptila caerulea*)	S	+	+	SB/SB
Chimney Swift (*Chaetura pelagica*)	S	+		B/F
Common Yellowthroat (*Geothlypis trichas*)	S	+		B/S

[6] Note that data from the dry uplands in the eastern section of Hollow Rock Nature Park are left out of the analysis since no earlier surveys were done in that area.

Breeding Birds				
Species	**Residency Status**	**1992-2005**	**2021-2022**	**Comments**
Hooded Warbler (*Setophaga citrina*)	S	+		SB/S
Indigo Bunting (*Passerina cyanea*)	S	+	+	B/SB
Kentucky Warbler (*Geothlypis formosa*)	S	+		SB/S
Northern Parula (*Setophaga americana*)	S	+	+	SB/SB
Ovenbird (*Seiurus aurocapilla*)	S	+		B/S
Red-eyed Vireo (*Vireo olivaceus*)	S	+	+	SB/SBF
Scarlet Tanager (*Piranga olivacea*)	S	+	+	B/SBF (one breeding season record at Hollow Rock)
Summer Tanager (*Piranga rubra*)	S	+	+	B/SBF
Wood Thrush (*Hylocichla mustelina*)	S	+		SB/S
Yellow-billed Cuckoo (*Coccyzus americanus*)	S	+	+	B/BF

Seven species that were recorded in the earlier period were not recorded in the current survey. In the case of American Woodcock and Chimney Swift, the species could have been easily overlooked. This is unlikely to be the case, however, for the remaining five species: Wood Thrush, Common Yellowthroat, Ovenbird, Hooded Warbler, and Kentucky Warbler, all of which are diurnally active and announce the defense of their breeding territories by song. The first three of these species were heard on the study area in 2022 during the migratory period but not thereafter.

Also recorded in the study area during the migratory period but not during the breeding period were American Redstart and Yellow-throated Vireo. Although neither of these species were recorded in the earlier survey period, both were regular nesting species during that time in the floodplain forest at the Mason Farm Biological Reserve and would be expected to nest within the New Hope project area as well. Additionally, the Prothonotary Warbler was also seen on one occasion during the migratory period but not later in the breeding period. Although not a regular nesting species at Mason Farm, it regularly nests within the bottomland forests located along the tributaries of Jordan Lake and certainly seemed to have suitable nesting habitat in the New Hope study area.

Altogether, ten species that were expected to occur as nesting species were not recorded during the current survey and one other species, Scarlet Tanager, was recorded only once during the breeding period at Hollow Rock Nature Park but only during the migratory period in the New Hope Bottomlands.

Countering this trend of losing species, several birds appear to have recently become regularly breeding species in the study area. These include Yellow-crowned Night Heron, Great Blue Heron, Canada Goose, Fish Crow, and Song Sparrow. With the exception of the Night Heron,

which migrates south in the winter, all of these species now appear to have joined the group of permanent residents of the study area.

Apart from these additions, the group of permanent residents has remained very consistent over the past thirty years: of the 39 species found in our area, only two primarily forest species, American Woodcock and Eastern Screech Owl, were not observed in 2021-2022 and both of them are fairly easily missed. Four other species associated primarily with open habitats were also missed, including Loggerhead Shrike, Northern Bobwhite, Eastern Meadowlark, and Barn Owl. However, apart from the powerline corridor, habitat is largely missing for those species in the study area.

Winter residents, which consist of species that migrate into our area from further north, also consist of a mixture of long-standing members and some that appear to be declining. Fifteen species were recorded in the study period, including such noteworthy species as Sharp-shinned Hawk, Rusty Blackbird, and Hooded Merganser. Species that were missed include Evening Grosbeak, Red-breasted Nuthatch, Purple Finch, and Pine Siskin.

Species that are purely migratory in our area were not a main focus of our survey. However, the number recorded in our survey or in the eBIRD records from the project area appears to have declined. Only seven species were recorded in the study period and several formerly common migrants were missed, including Swainson's Thrush, Rose-breasted Grosbeak, and Blackpoll Warbler.

Conservation Concerns

Although more surveys will need to be conducted to confirm the trends noted above, the results we obtained are certainly consistent with the trends in bird populations observed nationwide, i.e., those that have resulted in a net reduction in bird numbers by 3 billion over the past 30 years. The changes in abundance described by Rosenburg et al. (2019) all seem evident: migratory species show the greatest degree of decline, with Neotropical migrants – our summer residents and purely migratory species – showing the highest proportion of decline. Permanent resident, on the other hand, appear to be either stable or even increasing, possibly the result of decreased competition from the migratory species. Taxonomically, water birds appear to be one of the few groups that are increasing, due to better wetland management, improvements to water quality, and especially due to the return of beaver ponds to the landscape.

The reasons for the massive declines in the migratory land birds are more difficult to explain, with a number of different causes being proposed. Loss of wintering habitat in the tropics and increased hazards during migration aside, there are changes in the breeding habitat that are of particular concern in this site-focused study.

On the breeding grounds, outright loss, fragmentation, and degradation of habitats are major factors. Over the past thirty years, the New Hope valley has been transformed from a largely

rural area to one that is becoming rapidly urbanized. Large areas of forest have been permanently converted to residential and business uses, all the way up to the very edges of the New Hope floodplain. Impacts due to increased disturbance, greater exposure to nest parasitism by Brown-Headed Cowbirds, and more competition with exotic species – particularly Starlings – for nesting sites and other resources, are likely to have an effect on all birds nesting within the bottomlands. The same is true for increased predation by domestic cats, although the population of Coyotes within the bottomlands may be countering that particular threat (see summary for Mammals).

Another factor documented in our multi-taxa inventory, however, may dwarf all other impacts: the massive decline in the number of insects, the principal food used by the majority of birds. The moth surveys in particular, found only a small fraction of the number of individuals and species expected for brownwater floodplain forests in North Carolina (see summary for Moths).

The disparity between observed and expected numbers was seen throughout the growing season but was particularly severe in May, when a massive increase in the number of moths usually occurs in response to the leafing out of hardwood species of trees and shrubs. This dearth of moths – or more particularly – their caterpillars during what would normally be the spring flush is likely to have an especially profound effect on Neotropical migrant, forest-interior-nesting birds. These species expend a huge amount of energy in making the migration up from their wintering grounds; some species flying more than 1000 miles in their journeys north. The timing of their migration normally causes them to reach their breeding grounds in temperate forests just when the number of caterpillars reach their peak. They are also able to take advantage of this abundant food source to bring off one or more clutches of young and then to fatten back up in time for the return migration to the south. In other words, this entire phenomenon – one of the most impressive movements of animals on the planet -- works due to the normally close coupling of avian and insect phenologies. When that coupling fails, catastrophic consequences should be expected.

Although this failure of the food supply affects all bird species (as well as other groups of insectivores), permanent residents are probably affected less, since they do not need to build up their fat reserves to fuel immense migratory journeys. They often begin nesting well in advance of the spring flush and can pull off more clutches due to their lack of need to build up their reserves for return journeys south. Even so, some declines would be expected to occur in this group, although possibly offset by decreased competition for food due to the even sharper decline in the migratory species.

Still further impacts are expected due to global climate change; increased temperatures, droughts, floods, and potentially wildfires are all likely to affect birds directly, as well as well as indirectly through their habitats and food supplies. Impacts due to increased frequency and severity of flood events may be already occurring in the New Hope bottomlands (see discussion in the Moths summary). Increased flooding is especially likely to affect ground- or low-nesting species, such as Ovenbird, Kentucky Warbler, Common Yellowthroat, and Wild Turkey. Due to

the large number of potential factors responsible for bird declines, however, it is difficult to discern this effect by itself.

Conservation Recommendations

1. Reduce habitat fragmentation and edge effects. Protect more land as buffers for the existing tracts in conservation management. Allow buffers of native trees and shrubs to develop in areas where they have been cleared in between residential areas and businesses and the preserves. Protect any areas that increase the amount of land in conservation, particularly tracts that are contiguous with existing protected lands or that serve to connect them. Find alternative routes for new roads, powerlines, sewer lines, and other infrastructure that avoid the conservation lands.
2. Maintain or restore natural vegetation. Eradicate exotic invasives that provide little, if any, food for native insects and replace them with native species, particularly those that are rich in terms of native insect herbivores. In the bottomland forests, restore the natural, multi-layered structure. In the powerline, enhance natural habitats by allowing marshes or beaver ponds to develop in open wetland areas. Allow shrubs and trees to grow within herbicide-free patches may also allow species associated with successional or edge habitats to occupy the area. Maintain the deer herd at a natural level in order to restrict the impacts of their browsing.
3. Reduce stormwater runoff from adjoining developed areas. Use permeable surfaces for parking areas. Plant only native species in stormwater detention ponds.
4. Limit the height of buildings next to natural areas in order to reduce light pollution. Use bird-safe window designs to prevent collisions.
5. In residential areas, landscape using native species. Avoid the use of pesticides and other landscaping chemicals. Prevent buildup of predators by not leaving pet foods outside; use fences to separate residences separate from adjoining natural areas. Keep domestic cats and dogs under control.
6. Carefully site trails in order to prevent disturbance of nesting habitats. Prohibit the use of off-road vehicles in preserves.
7. Monitor bird populations, including those belonging to all four residency classes. Give more attention to nocturnal species.

References:

Narango, D.L., Tallamy, D.W. and Marra, P.P., 2018. Native plants reduce population growth of an insectivorous bird. Proceedings of the National Academy of Sciences, 115(45), pp.11549-11554. Available online at: https://www.pnas.org/doi/full/10.1073/pnas.1809259115

American Bird Conservation Initiative. 2022. The State of the Birds, United States of America, 2022. Available online at: https://www.stateofthebirds.org/2022/wp-content/uploads/2022/10/state-of-the-birds-2022-spreads.pdf

Rosenberg, K.V., Dokter, A.M., Blancher, P.J., Sauer, J.R., Smith, A.C., Smith, P.A., Stanton, J.C., Panjabi, A., Helft, L., Parr, M. and Marra, P.P., 2019. Decline of the North American avifauna. Science, 366 (6461):120-124. Available online at: https://www.birds.cornell.edu/home/wp-content/uploads/2019/09/DECLINE-OF-NORTH-AMERICAN-AVIFAUNA-SCIENCE-2019.pdf

Şekercioğlu, Ç.H., Daily, G.C. and Ehrlich, P.R., 2004. Ecosystem consequences of bird declines. Proceedings of the National Academy of Sciences, 101(52), pp.18042-18047. Available online at: https://www.pnas.org/doi/full/10.1073/pnas.0408049101

Mammals

Biology and Characteristics

Mammals are the most familiar group of animals and are typically the species that get the most of our attention in conservation efforts -- there are very few of us who have not heard about the plight of Elephants, Polar Bears, or Mountain Gorillas, all of which belong to what has been termed the Charismatic Megafauna. This prominence of mammals gives them a flagship role in gathering public support for conservation, which is vital for the protection of all biodiversity.

Although lower in diversity and abundance than several of the other taxonomic groups included in this study, mammals make up for those deficits in their much larger size and in some of the ecological functions that their size and high metabolic levels allow them to perform. The central role that Beavers play in creating pond, marsh, and shoreline habitats is a major example. Their return to the bottomland landscape, following their near extirpation from the continent at the end of the 19th Century, is one of the few bright spots for biodiversity: many of the taxonomic groups associated with beaver-created wetlands are actually increasing in diversity and abundance, in sharp contrast to the declines of many other groups.

Top carnivores also play keystone ecosystem roles by regulating the populations of species lower down in the food web. This is clearly seen where they have been eliminated from the landscape. The great proliferation of the deer population – now causing significant declines in the diversity and abundance of woodland herbs and shrubs – is a direct consequence of the loss of Wolves and Mountain Lions from our area. While there are understandably no plans to re-introduce Wolves to the New Hope Bottomlands, we probably need to consider how well Coyotes may be able to fill this key role.

Yet one other, more benign but key role that mammals play is the dispersal of seeds by Squirrels and other rodents, as well as by omnivores such as Opossums, Raccoons, and Foxes. In the New Hope Bottomlands, the wide distribution of both Pawpaw and Big Shellbark Hickory is the direct result of the mutualistic service these mammals provide; the mammals harvest fruit and nuts as food, but their transportation of either indigestible seeds or difficult-to-open nuts into new areas has major benefits to the plants. The mammalian dispersal of spores of several species of subterranean fungi also depends on this form of symbiosis. Overall, mammals are far more important for the conservation of ecosystems than just their familiar faces and endearing behaviors.

Survey Efforts

The focus of our inventory efforts was on the medium-sized to larger species of mammals, specifically those that can be surveyed by direct observation or by using tracks and sign or trail cameras (“trail cams”). Although the smaller species – including Insectivores and Rodents – are the most diverse group of mammals, they require the use of traps or other specialized

techniques to sample them, which we chose not to employ. Recording bats also requires special equipment and were consequently not included in our survey.

Track-and-sign surveys were also used in the Durham County Wildlife Inventory conducted in the 1990s (Hall, 1995) and in the reconnaissance surveys of the Hollow Rock tracts in the early 2000s (Hall, 2005). Site visits where mammal records were obtained in those surveys are listed in the following table:

Mammal Records 1992-2005		
Visit Date	**Site**	**Number of Species**
1992-04-03	Mt. Moriah Bottomlands	6
1992-04-16	Old Chapel Hill Road Bottomlands	7
1992-06-19	Old Chapel Hill Road Bottomlands	5
1992-07-15	Mt. Moriah Bottomlands	8
1994-01-25	Mt. Moriah Bottomlands	10
1994-01-25	New Hope Bottomlands	7
1994-04-06	Old Chapel Hill Road Bottomlands	5
1994-04-09	Old Chapel Hill Road Bottomlands	2
2005-04-21	Hollow Rock Nature Park	6

Additional data from the early 2000s comes from a study by Kleist et al. (2007), who monitored the species using the newly constructed wildlife passage under the bridge over New Hope Creek at US 15-501. That study relied on both direct observations, including road kills, and trail cams for their records. Of the ten species recorded in that study, three were not otherwise recorded in the project area (all road kills).

More recently, a camera study was conducted at the same location by Ron Sutherland (2022), from May 2017 to August, 2019. This survey involved the use of 12 cameras mounted under the US 15-501 bridge and obtained over 4,000 observations. Also, during the time period immediately prior to the start of the current survey, fifty-one track records were obtained in a preliminary mammal survey of the New Hope Bottomlands conducted by Steve Hall, John Kent, and Andy Riddle between March, 2019 and July, 2021.

Track surveys were done in the current survey by Steve Hall. Almost all of these records come from the New Hope Bottomlands. The plentiful mud in that area, particularly during the winter and early spring, make this a particularly productive site for tracking surveys; the mostly upland trails at the Hollow Rock Nature Park were much less so.

Additional records from the New Hope Bottomlands come from a trail cam operated by Brendan Moore of the Durham Open Space Program. This camera was positioned along a regularly used trackway, located along a flood channel that connected New Hope Creek to a series of marshes and sloughs located in the central and west sides of the tract. Records based on direct observations were also made – Eastern Gray Squirrels, for instance, were seen on virtually all visits to the project area. Acoustic records of Coyotes were also made on several occasions, mainly when a family group was stimulated to howl in response to a vehicular siren being sounded on US 15-501.

Observations were made on an opportunistic basis throughout the study. Surveys that were specifically focused on tracking were done mainly during the winter months, when tracking conditions were at their best. Days when five or more observations were recorded – indicating the more intensive tracking efforts -- are listed below.

Mammal Records

2019-22

Visit Date	Site	Number of Species
2019-03-18	New Hope Bottomlands	12
2019-04-29	New Hope Bottomlands	8
2020-01-17	New Hope Bottomlands	11
2020-02-17	New Hope Bottomlands	7
2020-03-02	New Hope Game Land	5
2020-05-15	New Hope Bottomlands	10
2021-09-07	New Hope Bottomlands	7
2021-11-09	New Hope Bottomlands	5
2022-03-15	New Hope Bottomlands	7
2022-04-03	New Hope Bottomlands	7
2022-04-05	New Hope Bottomlands	5
2022-05-16	New Hope Bottomlands	6
2022-05-23	New Hope Bottomlands	6

In addition to the records obtained from the sources just described, records submitted to iNaturalist were also examined. However, no new species – including small mammals or bats – were added based on these data.

Summary of the Mammal Species Recorded in the Project Area

A total of nineteen species of mammals have been recorded within the project area. These are listed below, along with the number of dates of observations (note that Eastern Gray Squirrels and White-tailed Deer, were observed on far more occasions than were recorded). Observations marked with an asterisk come solely from the survey conducted by Kleist et al. (2007) or Sutherland (2022). All species included on this list are native except for Domestic Cat. That species was included due to the conservation concerns they pose and since they can become feral. Domestic Dogs were also commonly recorded, but probably mainly, if not always, in the company of humans, which are not listed here.

Order	Species	Number of Observations
Didelphimorphia	Virginia Opossum (*Didelphis virginiana*)	17
Soricomorpha	Eastern Mole (*Scalopus aquaticus*)	10
Rodentia	American Beaver (*Castor canadensis*)	24
Rodentia	Common Muskrat (*Ondatra zibethicus*)	10
Rodentia	Eastern Chipmunk (*Tamias striatus*)	1*
Rodentia	Eastern Gray Squirrel (*Sciurus carolinensis*)	28
Rodentia	Hispid Cotton Rat (*Sigmodon hispidus*)	1*
Rodentia	Southern Flying Squirrel (*Glaucomys volans*)	2
Rodentia	Woodchuck (*Marmota monax*)	1*
Lagomorpha	Eastern Cottontail (*Sylvilagus floridanus*)	15
Carnivora	Bobcat (*Lynx rufus*)	2
Carnivora	Domestic Cat (*Felis catus*)	1*
Carnivora	Common Raccoon (*Procyon lotor*)	26
Carnivora	American Mink (*Neovison vison*)	9
Carnivora	North American River Otter (*Lontra canadensis*)	14
Carnivora	Coyote (*Canis latrans*)	21
Carnivora	Gray Fox (*Urocyon cinereoargenteus*)	5
Carnivora	Red Fox (*Vulpes vulpes*)	3
Artiodactyla	White-tailed Deer (*Odocoileus virginianus*)	30

Noteworthy Species

None of the species recorded in the project area are considered to be of conservation significance at the state level: none are ranked as high as S3 by the Natural Heritage Program. Only three such species have, in fact, been recorded in Durham County or the adjoining areas (see Mammals of North Carolina website): Meadow Jumping Mouse (*Zapus hudsonius*), ranked as S1; Tricolored Bat (*Perimyotis subflavus*) ranked as S3; and Long-tailed Weasel (*Mustela frenata*) ranked as S3. Long-tailed Weasel was one of the species that we looked for specifically, since an observation of this species was made in the New Hope watershed in the last 15 years (Norm Budnitz, pers. comm. to S. Hall). No tracks or scats of this species were observed, however.

Otter (*Lontra canadensis*) and American Mink (*Neovison vison*), were recorded on a number of occasions. Otter, in particular, appear to be common in the study area, with tracks and sign findable virtually every day of the year.

The most uncommon species recorded in the project was Bobcat (*Lynx rufus*), state-ranked as S4. Although still widespread across the state, this species is sensitive to human disturbance and is declining in areas that have become fragmented as the result of development. We found only one set of tracks during the current survey and no observations were made in either of the two US 15-501 underpass studies (Sutherland, however, recorded it downstream at the NC 54 bridge, where other recent records also exist).

Two other species ranked as S4, Northern River

Comparison to Past Results

All of the species recorded previously in the study area during the Durham County Wildlife Survey (Hall, 1995) were observed during the current study. Only four species recorded by Kleist et al. (2007) were not observed: Domestic Cat, Eastern Chipmunk, Woodchuck, and Hispid Cotton Rat. Chipmunks are associated primarily with upland stands of hardwoods and were recorded at a time when there were still extensive slopes located adjacent to the New Hope floodplain. While this species is still potentially present in the Hollow Rock Nature Park (although not recorded there or in the adjacent areas by iNaturalist), much of the uplands along the west side of the New Hope Bottomlands have been developed since the time of Kleist's study, leaving only a narrow strip of forested slope next to the bottomlands. Woodchuck and Hispid Cotton Rats, on the other hand, are associated with open, old field habitats and could be expected to benefit from the creation of new edge habitats. Given their habitat preferences, none of these species, however, are likely to have been recorded in the track-based surveys conducted down in the muddy floodplain and need to be surveyed by other methods.

The absence of these three native species and Domestic Cat, in any case, does not indicate that any significant decline has taken place in the mammal fauna of the study area over the past thirty years. On the other hand, the arrival of Coyotes in this area during this time period does indicate a significant change. Although present in some areas of the state back in the 1990s, no tracks of this species were recorded in the Durham County Wildlife Survey, whereas now their tracks are one of the most commonly encountered in the project area. This was the second-most common species recorded at the US 15-501 study by Sutherland, with over 200 observations (records for deer numbered greater than 2000).

The advent of Coyotes in our area represents at least a partial re-filling of the niche once occupied by Wolves (Red and/or Gray), restoring a species capable of preying on deer, if mainly fawns in the case of Coyotes. Given the massive impacts to the vegetation caused by deer over-proliferation, any control on their populations should be seen as beneficial, although it is unclear if Coyotes are actually capable of reducing deer populations (see Bragina et al., 2019).

The same “release” from the apex predators that led to expansions of the deer herd and the eastward movement of Coyotes probably also allowed the invasion of our area by Red Fox, which was unknown in the Southeast when the area was first colonized. Other meso-carnivores – which include Gray Fox, Raccoon, Striped Skunk, Otter, Mink, and Long-tailed Weasels – may also have been released -- expanding their populations -- with increased impacts to their own prey species (Crooks and Soule, 1999).

Competition with Coyotes, which can involve their killing smaller carnivores, may conversely reduce the numbers of other meso-predators, with possible beneficial effects on their prey. Gray Foxes, in particular, have been found to decline following the arrival of Coyotes (Egan et al., 2021; but see Parsons et al., 2018, for contrary findings). No sign of that species was, in fact, found during the current inventory, although their tracks were recorded in the area as recently as 2019. The same was true for Domestic Cat, despite the fact that their numbers are expected to increase due to the large number of residences that have recently been constructed adjacent to the New Hope Bottomlands. Only single tracks of Red Fox and Bobcat were recorded in the survey (along the edge of the bottomlands), but these species were only infrequently recorded

in the past. No noticeable changes were observed in the frequency of observation of the tracks of Raccoon, Opossum, Mink, or Otter, all of which are less direct competitors with Coyotes than are the two foxes. Whether Coyotes will have any significant impacts on the biodiversity of the New Hope Bottomlands – positive or negative – remains to be determined.

Overall Quality of the Mammalian Community; Comparison to Other Sites

A total of fifty species of mammals have been recorded in Durham, Orange, Chatham, and Wake Counties (see Mammals of North Carolina Website). Subtracting bats, rodents, insectivores, and a few larger species such as Black Bear and the recently arrived Nine-banded Armadillo, only three species of mammals were missed in the current study that had a chance of being detected: Long-tailed Weasel, Striped Skunk, and Marsh Rabbit. Although not recorded in the earlier surveys within the study area, all have been recorded elsewhere in the Triassic Basin Lowlands. Striped Skunks are occasionally killed along I-40 at the downstream crossing of New Hope Creek (Hall, pers. obs.). Long-tailed Weasels have been reported at the Mason Farm Biological Reserve in the 1980s (David Westneat, pers. comm. to S. Hall) and near the Durham Division of Duke Forest in the 2010s (Norman Budnitz, pers. comm. to S. Hall). Marsh Rabbits have been observed at Mason Farm since the 1970s (Sather and Hall, 1988) and still seem to have a resident population at that site.

The absence of both Striped Skunk and Long-tailed Weasel may be more of a sign of regional- or state-wide decline rather than one that is localized to the New Hope study area. The populations of Striped Skunk appear to fluctuate in the southeastern Piedmont and Coastal Plain (Mammals of North Carolina Website, accessed 2022-11-01), with no recent records from Durham County on iNaturalist (some are present in Orange County, however; accessed 2022-11-01). Long-tailed Weasel has apparently declined over an even larger area, with very few recent records in the state outside of the mountains (Mammals of North Carolina Website, accessed 2022-11-01). As discussed below, this species appears to be declining over much of eastern North America, consistent with the pattern of mammal decline observed world-wide.

The absence of Marsh Rabbits, however, may be due to local habitat factors, particularly the lack of large beaver-created pond and marsh complexes such as have existed in the Morgan Creek drainage since at least the 1970s (Hall, pers. obs.), when, in fact, Marsh Rabbits were first discovered at Mason Farm. While beavers are common in the New Hope project area, the ponds and marshes they create are not. Cattails – one of the major food items used by Marsh Rabbits -- are nearly completely missing from the study area, with only a very few stems having been observed in wet areas located under the powerline. The absence of Cattails and possibly other marshland plants may, in fact, be due to the application of herbicides used to suppress the growth of shrubs and trees beneath the powerline. Cattails, Pickerel Weed, Water Lily, Arrowhead, and Duckweed are all known to be susceptible to imazapyr-based herbicides such as Arsenal (WDNR, 2022), a weed-killer widely used to control woody shrubs and trees. Whether this or some other cause is responsible for the scarcity of marsh habitats in the study area needs more investigation. More study is also needed to confirm that Marsh Rabbit is

completely missing from the New Hope Creek watershed, or just within the areas where the powerline is located.

Mason Farm -- the natural area with the greatest similarity to the New Hope project area in terms of geography and habitats –differs from the New Hope study area in one other significant way: its possession of a resident population of Bobcat. Tracks of this species were regularly observed at Mason Farm in the 1980s (Hall, pers. obs.) and this species continues to be regularly recorded at that site (R.H. Wiley and Bo Howse, pers. comm. to S. Hall). This contrasts with the apparent transient presence of this species within the New Hope Bottomlands, or at least the portion included in the project study area.

This difference may reflect that Mason Farm is located in a much broader tract of wild lands than the narrow strip of habitat remaining in the New Hope Bottomlands. Bobcats are known to be highly area-sensitive in terms of their habitat uses; tracts of habitat that are too small or narrow are typically avoided. Another factor is the greater amount of early successional habitats – old fields – that Mason Farm possesses; these are prime hunting grounds for Bobcats due to their large populations of Cotton Rats and Cottontails, two of their most important prey species in our area. Except for the old fields that border the Mt. Moriah Bottomlands on the west side of the floodplain where, in fact, Bobcats were recorded by Hall in 2007, old field habitats have mostly succeeded to forest along the New Hope Bottomlands, with many of these upland sites now largely converted to development.

Although the greater habitat diversity and its wider buffers from human disturbance may make Mason Farm more significant as a reservoir area for the area's mammals, the New Hope Bottomlands nonetheless perform a key function in linking together areas that form an even larger complex of natural areas. For species such as Bobcat to persist in the large tracts of conservation lands located in Duke Forest and the Johnston Mill Preserve to the north of US 15-501 -- otherwise surrounded by major highways -- maintaining the connector function provided by the New Hope Bottomlands is absolutely critical.

Conservation Concerns

Worldwide, mammalian biodiversity is undergoing the same massive decline as observed in birds and other wildlife (Andermann, et al., 2020; Ritchie and Roser, 2021; Stein et al., 2018). In our study, the possibly complete loss of Long-tailed Weasel and the extreme scarcity of Bobcat – both of which once occurred across the entire state and occupied a wide range of habitats – are the best examples of this trend. Both of these species are secretive – as viewed by most humans – and their population trends have been difficult to monitor except through trapping reports. In the case of the Weasel, the decline appears to have been taking place for a long time, a trend that has largely gone unnoticed even by wildlife biologists. In a review of all available evidence, including trapping results, Jachowski et al. (2021) found that they are not simply just very good at escaping detection but that they are actually disappearing from the landscape.

That probably is not the case for Bobcat, whose tracks, at least, can be detected more widely across the state, at least in areas that are not undergoing rapid urbanization. In developed areas, on the other hand, they are probably just as much true ghost species as the Long-tailed Weasel.

For the species of mammals considered in this report, loss, degradation, and fragmentation of their habitat due to human activities is the most critical factor (Laliberte and Ripple, 2004). A close second is the fact that all of these species are hunted as either game species or fur-bearers. These two factors combine, in that several of these species can now maintain viable populations only in large tracts of natural habitats that are difficult for humans – including hunters and trappers -- to access. While smaller tracts, if well protected, can also serve as refuges, those that are too close to human activities are actively avoided by species such as Bobcat or Long-tailed Weasel, particularly where there are no tenable connections to larger blocks of habitat.

Even in large and/or well-connected clusters of natural areas, the disruptions caused by the loss of apex predators; the arrival of exotic species such as Coyotes, Red Foxes, and domestic dogs and cats; and the diseases – e.g., rabies, distemper, and now COVID -- that many of these species exchange are having impacts on biodiversity that are still playing out. Closer monitoring of the mammalian fauna within natural areas is currently a very much unmet need. Surveys need to be done much more frequently than once every thirty years. They also need collect quantitative data, i.e., information on population sizes and trends, rather than just the presence/absence of the individual species.

Small mammals also need to be included in these monitoring efforts. This especially crucial in the case of bats: this is now the most imperiled group of mammals in North America due to the onslaught of the White-nosed Disease, which is particularly severe in species that congregate in caves to overwinter. While this is likely to be less of a factor for species such as Eastern Red Bat (*Lasiurus borealis*) and Evening Bat (*Nycticeius humeralis*) that are forest-dwellers, the same disastrous decline that we have observed in the avifauna due to the crash in moth populations may be affecting them as well.

Conservation Recommendations

1. Conserve large blocks of habitat with wide buffers separating them from developing areas. Wide buffers are also needed between natural areas and farmlands where intensified agricultural methods – involving large amounts of agricultural chemicals – are applied. Buffers are less needed or even undesirable where more traditional, or organic farming methods are practiced.
2. Where buffers are not possible, use fences – including Coyote and Deer-proof fences – to separate human populations and their pets from natural areas. This is needed both to keep the wild species from invading yards and neighborhood streets and to keep dogs, at least, from straying into the adjoining natural areas. Cats should be kept in-doors,

both for their own safety and to limit their depredations of native species. Wildlife should never be fed and pet food should not be left outside and unattended.

3. Limit access into natural areas to just a few entry-ways and keep trails away from sensitive denning or foraging areas for wildlife. Do not allow dogs to run off-leash within protected natural areas.
4. Prohibit the use of poisons or snares to control wildlife, particularly in areas that adjoin natural areas. For Coyote control, follow the integrated pest management guidelines such as recommended by Breck et al. (2017) and Mitchell et al. (2004).
5. Eliminate the use of herbicides that have impacts on marshland vegetation and herbaceous species in general. At the very least, use other methods to suppress woody species where wetlands are present under the powerline, including the channels that distribute floodwaters throughout the system of ponds and sloughs that occur throughout the New Hope floodplain.
6. Conduct frequent monitoring of Mammal populations in order to assess changes that need to be addressed through management actions. Determine the status of the bat and small mammal populations in particular.

References

Andermann, T.; Faurby, S; Turvey, S.T; Antonelli, A. and Silvestro, D. 2020. The past and future human impact on mammalian diversity. Sci. Adv. 6, eabb2313. Available online at: https://www.science.org/doi/epdf/10.1126/sciadv.abb2313

Bragina, E.V., Kays, R., Hody, A., Moorman, C.E., Deperno, C.S. and Mills, L.S., 2019. Effects on white-tailed deer following eastern coyote colonization. The Journal of Wildlife Management, 83(4):916-924. Available online at: https://faculty.cnr.ncsu.edu/christophersdeperno/wp-content/uploads/sites/8/2019/07/PR138-Bragina-Coyotes-and-deer-JWM.pdf

Breck, S.W., Poessel, S.A. and Bonnell, M.A., 2017. Evaluating lethal and nonlethal management options for urban coyotes. Available online at: https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=2983&context=icwdm_usdanwrc

Crooks KR, Soule ME (1999) Mesopredator release and avifaunal extinctions in a fragmented system. Nature 400:563–566. Available online at: https://www.originalwisdom.com/wp-content/uploads/bsk-pdf-manager/2019/03/Crooks-and-Soule_1999_Mesopredator-release-and-avifuanal-extinctions-in-a-fragmented-system.pdf

Dewey, et. al. “Beaver dams overshadow climate extremes in controlling riparian hydrology and water quality.” Nature Communications. Nov. 8, 2022. Available online at: Beaver dams overshadow climate extremes in controlling riparian hydrology and water quality | Nature Communications

Egan, M.E., Day, C.C., Katzner, T.E. and Zollner, P.A., 2021. Relative abundance of coyotes (Canis latrans) influences gray fox (*Urocyon cinereoargenteus*) occupancy across the eastern United States. Canadian Journal of Zoology, 99(2):63-72.

Hall, S.P. 1995. Inventory of the Wildlife Habitats, Movement Corridors, and Rare Animal Populations of Durham County, North Carolina. Unpubl. Report. NC Natural Heritage Program, Durham County Inventory Review Committee, Triangle Land Conservancy. [Note that the results of this survey were included in the combined report by Hall and Sutter, 1998; however, that report does not contain the species lists present in the earlier version.]

Hall, S.P.; Jones-Roe, C.; and Wiley, R.H. 1986. Vertebrates (other than birds) of the Mason Farm Biological Reserve and adjacent areas. Friends of Mason Farm.

Ritchie, H. and Roser, M. 2021. Mammals - Our World in Data. In: Biodiversity. Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/biodiversity' [Online Resource]. Available online at: https://ourworldindata.org/mammals

Jachowski, D., Kays, R., Butler, A., Hoylman, A.M. and Gompper, M.E., 2021. Tracking the decline of weasels in North America. PloS one, 16(7), p.e0254387. Available online at: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0254387

Laliberte, A.S. and Ripple, W.J., 2004. Range contractions of North American carnivores and ungulates. BioScience, 54(2):123-138. Available online at: https://academic.oup.com/bioscience/article/54/2/123/255016

Mitchell, B.R., Jaeger, M.M. and Barrett, R.H., 2004. Coyote depredation management: current methods and research needs. Wildlife Society Bulletin 32(4):1209-1218. Available online at: https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1602&context=icwdm_usdanwrc

Parsons, A.W., Rota, C.T., Forrester, T., Baker-Whatton, M.C., McShea, W.J., Schuttler, S.G., Millspaugh, J.J. and Kays, R., 2019. Urbanization focuses carnivore activity in remaining natural habitats, increasing species interactions. Journal of Applied Ecology, 56(8:1894-1904. Available online at: https://besjournals.onlinelibrary.wiley.com/doi/pdfdirect/10.1111/1365-2664.13385

Sather, D. and Hall, S. 1988. Inventory of Natural Areas and Wildlife Habitats for Orange County, North Carolina. Unpubl. Report to the Triangle Land Conservancy. North Carolina Natural Heritage Program, Raleigh, N.C. [Species lists are available only from the original version and are not included in the update done in 2004 by Sorrie and Shaw].

Stein, B. A., N. Edelson, L. Anderson, J. Kanter, and J. Stemler. 2018. Reversing America's

Wildlife Crisis: Securing the Future of Our Fish and Wildlife. Washington, DC: National Wildlife Federation. Available online at: https://www.nwf.org/-/media/Documents/PDFs/NWF-Reports/2018/Reversing-Americas-Wildlife-Crisis_2018.ashx

Sutherland, Ron (2022). Comparison of wildlife passage under two highway bridges along New Hope Creek. Unpublished report from Wildlands Network.

WDNR (Wisconsin Department of Natural Resources). Imazapyr Chemical Fact Sheet. Available online at: https://dnr.wi.gov/lakes/plants/factsheets/ImazapyrFactsheet.pdf

Summary of Results and Conservation Assessment

The goals of this survey were to document the biodiversity that currently exists within the series of conservation lands located along New Hope Creek in Durham County. We sought to update the information from the earlier surveys that provided the original justification for the conservation of these lands; to add new information based on inclusion of a much wider set of taxonomic groups; and to use this information to assess its current priorities for conservation action. We begin by summarizing the elements of biodiversity that we documented in the survey. This is followed by an interpretation of what these results mean in terms of ecosystem integrity.

Taxonomic Diversity

The following table summarizes the taxonomic diversity documented in this survey[7]. Lists of the species and their occurrences within the main sites covered in the survey are presented in the Appendixes located at the end of this report. The individual records are included in the website developed for this project.

Table 1. Tally of Species Recorded in the New Hope Creek Biodiversity Survey

TAXON	NUMBER OF SPECIES
PROTISTA	55
SLIME MOLDS	55
LICHENS	98
LICHENS	98
FUNGI	240
FUNGI	240
BRYOPHYTES	102
HORNWORTS	1
LIVERWORTS	20
MOSSES	81
VASCULAR PLANTS	348
FERNS	12
CONIFERS	3
HARDWOOD TREES	39
VINES	26
SHRUBS	41
GRAMINOIDS	37

[7] This list includes only species that were recorded during the inventory itself; historic records and those from iNaturalist are not included in these tallies. Groups indicated with an asterisk were not included as targets of this survey but were recorded incidentally during the project.

TAXON	NUMBER OF SPECIES
AQUATIC FORBS	8
FORBS	182
ANNELIDS	1
LEECHES*	1
MOLLUSKS	8
LAND SNAILS*	8
TARDIGRADES	3
TARDIGRADES*	3
CRUSTACEANS	1
CRAYFISH*	1
MYRIAPODS	12
MILLIPEDES	9
CENTIPEDES	3
ARACHNIDS	137
SPIDERS	122
MITES*	4
HARVESTMEN	7
PSEUDOSCORPIONS	4
INSECTS	684
ODONATES	37
ORTHOPTERANS	45
TRUE BUGS*	7
HEMIPTERAN HOPPERS	36
NEUROPTERANS*	1
SCORPIONFLIES*	1
FLIES*	47
BEETLES	21
MOTHS	398
BUTTERFLIES	37
SYMPHYTAN WASPS*	3
GALL WASPS*	1
ACULEATE WASPS*	7
ANTS*	1
BEES	42

TAXON	NUMBER OF SPECIES
VERTEBRATES	117
FISH	1
FROGS AND TOADS	10
SALAMANDERS	1
TURTLES	2
SNAKES	3
LIZARDS	2
BIRDS	85
MAMMALS	13
Grand Total	**1,806**

Species of Conservation Concern and Other Special Interest

The following table lists species considered to be of conservation concern by the North Carolina Natural Heritage Program. These include species that the Program has designated as Significantly Rare as well as species on their Watch List that have a state rank of at least S3 (= Vulnerable, at moderate risk of extirpation from the state).

Table 2. State-ranked Species that were recorded in the survey

Survey Group	Species	State Rank	Comments on status
Bryophytes	*Taxiphyllum alternans*	S1	Previously known in NC from one historic record from the mountains
Vascular Plants	Big Shellbark Hickory (*Carya laciniosa*)	S1	Currently known in NC only from the New Hope Bottomlands and the lower Roanoke River floodplain
Vascular Plants	White Nymph (*Trepocarpus aethusae*)	S1	Currently known in NC only from the New Hope Bottomlands
Birds	Yellow-crowned Night Heron (*Nyctanassa violacea*)	S2	
Bryophytes	*Brachelyma subulatum*	S2?	Endemic to the Southeast; not recorded in NC since 1985
Bryophytes	Faurie's hypnum (*Hypnum fauriei*)	S2?	Rare in the eastern Piedmont and Coastal Plain
Birds	Rusty Blackbird (*Euphagus carolinus*)	S3	Present only as a winter resident in our area
Odonates	Arrowhead Spiketail (*Cordulegaster obliqua*)	S3	
Vascular Plants	Dense-flower Smartweed (*Persicaria densiflora*)	S3	

Survey Group	Species	State Rank	Comments on status
Vascular Plants	Godfrey's Thoroughwort (*Eupatorium godfreyanum*)	S3	
Vascular Plants	Lewis's Heartleaf (*Hexastylis lewisii*)	S3	

The Big Shellbark Hickory is the species discovered during the 1990s that contributed to the original high priority for conservation of the New Hope Bottomlands. It still has a vigorous population at this site and the survey extended its range into the Mt. Moriah Bottomlands north of the Durham-Chapel Hill Boulevard. Pyne and White's discovery of the White Nymph, which has just this one known population in North Carolina, adds greatly to the conservation significance of this site, as does our discovery of the rare moss, *Taxiphyllum alternans* and three species ranked as S2.

Several of the taxonomic groups included in the survey have not yet been assigned state conservation ranks by the Natural Heritage Program. The species considered noteworthy by those groups are listed in Table 3.

Table 3. Noteworthy species that have not been assigned state ranks

Survey Group	Species	Comments on status
Myxomycetes	*Stemonitopsis microspora*	New state record
Myxomycetes	*Cribraria oregana*	New state record
Myxomycetes	*Cribraria confusa*	Rare in NC
Myxomycetes	*Cribaria elegans*	Rare in NC
Myxomycetes	*Licea kleistobolus*	Rare in NC
Myxomycetes	*Licea biforis*	Rare in NC
Myxomycetes	*Oligonema flavidum*	Uncommon in NC
Myxomycetes	*Physarum polycephalum*	Only 5 records from NC; type locality is NC
Fungi	*Multifurca furcata*	Very rarely collected; type locality is New Hope watershed
Fungi	*Thyronectria aurigera*	New state record
Fungi	*Russula* (*Macowanites*)	Possible new species
Fungi	*Boletinellus merulioides*	Ash-specialist highly threatened by the Emerald Ash Borers; now known only historically from the project area
Lichens	*Calicium salicinum*	New county records; regionally rare
Lichens	*Scytinium lichenoides*	New county records; regionally rare
Lichens	*Bacidina delicata*	New county records; regionally rare
Lichens	*Bacidia purpurans*	New county records; abundant in the project area

Survey Group	Species	Comments on status
Lichens	*Micarea soralifera*	New state record; recently described (from Europe)
Myriapods	*Aniulus orientalis*	Known globally from only a few sites in North Carolina and Virginia
Arachnids	*Drassyllus ellipes*	New county record
Arachnids	*Agyneta parva*	Second state record
Arachnids	*Anthrobia acuminata*	New state record
Arachnids	*Souessoula parva*	New state record
Arachnids	*Lathys immaculata*	New state record
Arachnids	*Maymena ambita*	New state record
Arachnids	*Trebacosa marxi*	New state record
Arachnids	*Eidmannella pallida*	Only known in NC from a couple of counties
Arachnids	*Phrurotimpus annulatus*	New county record
Arachnids	*Marpissa lineata*	New county record
Arachnids	*Hyptiotes cavatus*	Only known from a few sites in NC
Arachnids	*Pisaurina brevipes*	New County and Piedmont record
Arachnids	*Trachelus similis*	New County record; only a few other records from the state
Micro-moths	*Marmara fraxinicola*	Ash-specialist highly threatened by the Emerald Ash Borer
Micro-moths	*Palpita magniferalis*	Ash-specialist highly threatened by the Emerald Ash Borer
Micro-moths	*Ancylis semiovana*	Only record from outside the mountains; threatened due to deer browsing on Ceanothus americanus
Micro-moths	*Omphalocera cariosa*	Known from only two sites in NC
Micro-moths	*Cosmopterix teligera*	Known from only two sites in NC
Micro-moths	*Anacampsis consonella*	New state record
Micro-moths	*Coptotriche purinosella*	Recently found in NC; few records
Micro-moths	*Helcystogramma hystricella*	Recently found in NC; few records
Micro-moths	*Phyllonorycter ostryaefoliella*	First recorded in NC at Leigh Farm; only known from three sites in NC
Micro-moths	*Marmara new species*	Apparently new to science
Leaf-mining Fly	*Ophiomyia new species*	Apparently new to science

Taken at face value, the small number of records for these species indicate that they would qualify for a state rank of at least S3. More surveys are needed, however in order to determine both the distribution and abundance of these species across the state, as well as their habitat associations. The species that appear to be completely new to science are particularly

noteworthy as taxonomic discoveries, but their significance for conservation still needs to be determined.

Habitat Diversity and Quality

The variety of habitats and other ecological groupings present in a given area are as important aspects of biodiversity as the variety of the taxonomic elements. For the New Hope Biodiversity Survey, we identified habitats following the definition used in the Habitats of North Carolina, a website being developed by the NCBP. Habitats in this approach are defined by both a set of habitat factors, which include biotic as well as abiotic criteria, and by a set of species that show particularly high fidelity to that set of factors: 80% or more of the occurrences of these species fall within areas where those factors prevail. Under this definition, habitats are mutually exclusive in terms of membership and can be recognized wherever there are members of its group of species present at a site. On the other hand, these habitats can overlap in space, corresponding to the intersection between the sets of habitat factors used to define these units.

In the New Hope Biodiversity study area, 61 such habitats were identified based on the species that have been recorded there (see list on the New Hope Biodiversity Project Website). The majority are general types of habitats that represent a wide range of forests, wetlands, fields, and edges. Of more particular interest to this project are the habitats associated with the most distinctive set of factors of the study area.

For the floodplain habitats that predominate in the New Hope and Mount Moriah Bottomlands, key habitat factors include both the frequent flooding typical of bottomland habitats in general and more specifically in its very rich sediments. Brownwater floodplains – carrying mineral-rich sediments weathered from the crystalline rock formations of the Piedmont and Blue Ridge – are usually rich in the nutrients plants need for growth, but the sediments in the project area appear to be especially fertile, based on the high number of basophilic plants that are present. Two of the most distinctive species of the study area, Big Shellbark Hickory and White Nymph, both appear to be restricted to floodplains possessing sediments with both a high nutrient content and a relatively high pH, either circumneutral or slightly basic. Other species that are particularly abundant in the New Hope floodplain include Reflexed Wild Ginger (*Asarum reflexum*), Smooth Yellow Violet (*Viola eriocarpa*), American Trout-lily (*Erythronium americanum*), and Spreading Chervil (*Chaerophyllum procumbens*).

By tracking the distribution of several of these species upstream, including Shellbark Hickory, they appear to be closely associated solely with sediments deposited by New Hope Creek and were not observed along the floodplain of Mud Creek at all. The main difference appears to be that New Hope has its headwaters in areas with extensive formations of mafic rocks, particularly the large gabbro sill at Meadow Flats in the Blackwood Division of Duke Forest. In

contrast, Mud Creek, which has its headwaters in the Durham Division of Duke Forest, appears to lack such a large source of mafic sediments.

One other noteworthy set of habitats found in the project area is located in the Durham County section of the Hollow Rock Nature Park. The upland ridge that extends east from Pickett Road to the Solterra development appears to possess a mixture of both mafic and acidic soils. Basophilic species such as Southern Shagbark Hickory (*Carya carolinae-septentrionalis*), Biltmore Ash (*Fraxinus biltmoreana*), Redbud (*Cercis canadensis*), and Hop-hornbeam (*Ostrya virginiana*) are present, along with acidophilic species as blueberries (*Vaccinium* species) and at least one patch of Lewis's Heartleaf (*Hexastylis lewisii*), an acidophilic species on the Natural Heritage Program Watchlist. Based on the list of species recorded at this site, the NCBP habitats listed for this area include Rich Dry-Mesic Hardwood Forests, General Dry-Xeric Hardwood Forests, and General Dry-Xeric Pine Forests.

Ecosystem Integrity

The integrity of an ecosystem rests on the stability of its ecological processes. These particularly include the transfer of energy and materials through the various trophic levels of the system and also the operation of mutualistic functions such as pollination, seed and spore dispersal, and the mycorrhizal associations between vascular plants and fungi. In all these cases, long histories of co-evolution play an important role, stabilizing both predator-prey interactions and competitive interactions between members of the same trophic level.

By including a wide array of taxonomic groups in our survey, we were able to examine the ecosystem integrity across all of the major trophic levels, as well as a large number of highly evolved, symbiotic associations. This analysis involves looking at the stability of the taxonomic groups both within and between the ecological strata composing the New Hope ecosystem.

PRIMARY PRODUCERS

For the most part, the composition of the vascular plants, bryophytes, and lichens – the main groups of autotrophs in terrestrial ecosystems – seems to be much the same as observed in previous surveys conducted in the project area or in surveys conducted in comparable habitats elsewhere in the region. Both the stands of floodplain forests in the New Hope Bottomlands and the stands of dry upland forests in the Hollow Rock Nature Park appear to have been relatively undisturbed for over a century. This is based on aerial photographs going back to the 1940s, showing extensive areas of closed canopy, hardwood dominated forests in these areas. The age of these stands is also supported by the presence of numerous trees that are over 15" in diameter (dbh), with individuals as large as three feet or more in diameter – including the state champion Big Shellbark Hickory – also found scattered throughout these stands.

However, there are now significant examples of destabilization taking place within the primary producers, and hence affecting the rest of the ecosystem. The most obvious are the result of introductions of exotic, invasive species, i.e., species that do not have long histories of co-evolution within our native ecosystems. The most dramatic – now involving the frequent crashing of dead snags – is the attack of the exotic beetle, the Emerald Ash Borer (*Agrilus planipennis*), affecting all of our species of ash (*Fraxinus* species). The damage done to the Green Ash (*Fraxinus pennsylvanica*) is especially severe in the bottomlands along New Hope Creek where it has been a main component of the rich floodplain habitats. Although not yet as noticeable, losses of White Ash (*F. americana*) and the uncommon Biltmore Ash (*F. biltmoreana*) are likewise taking place in the upland areas of Hollow Rock Nature Park. Other losses in that area may include Fringetree (*Chionanthus virginicus*), another member of the Olive Family that is attacked by this beetle.

Two of the least welcome discoveries made during the inventory were two new exotic species that could have similar widespread impacts to the plant species in the project area. One was a wilt affecting Spicebush (*Lindera benzoin*) that has been tentatively identified by the NCSU Plant Disease and Insect Clinic as an exotic fungus in the genus *Ceratobasidium*. The other – found in the same area – is a wilt affecting Pawpaw (*Asmina triloba*) and Greenbrier (*Smilax species*). This infestation was identified by the clinic as caused by the combined attack of an exotic ambrosia beetle, the Black Twig Borer (*Xylosandrus compactus*), and the symbiotic fungus (not yet determined) that it transmits and which its larvae feed upon. Although currently the victims of these wilts appear to be confined to the immediate vicinity of New Hope Creek, where increased flooding may be causing the host species to be weakened, if these pests are able to spread across the floodplain, then Pawpaws, Greenbriers, and Spicebushes – all major components of the floodplain forests -- may all be at risk, potentially along with a large number of other woody species; the *Ceratobasidium* wilt was initially discovered in North Carolina on nursery stock, including Redbud and Dogwood.

Also damaging are the impacts of exotic plant species, which lack the specialist herbivores present in their native habitats that serve to keep their populations under control. That lack of co-evolved stability gives species such as Chinese Privet (*Ligustrum sinense*) and Japanese Stilt Grass (*Microstegium vimineum*), a major competitive advantage over native species that do possess such controls. In some parts of the Mount Moriah Bottomlands, these species have completely swamped the herb and shrub layers and they now threaten to do so in the light gaps opened up by the destruction of the ash species. Unfortunately, another of the major changes we documented in our survey is the arrival of fifty species of invasive plants over the thirty years since the last plant surveys were done in this area. The arrival of Lesser Celandine (*Ficaria verna*) is an especial cause for concern, due the potential damage it could do to the rich herbaceous flora of the New Hope floodplain, including to the very rare White Nymph.

The arrival of these exotic species and their impacts are all too obvious. However, there are also absences of native plant species that appear to be significant: despite the presence of numerous pools and wetlands within the New Hope floodplain, Cattails (*Typha latifolia*) – a main constituent of fresh-water marshes – is nearly missing, along with a number of other marshland species. While not confirmed, we suspect this is due to the application of herbicides under the powerline that transects the New Hope and Mount Moriah Bottomlands. These chemicals are used to suppress the growth of woody species that could have impacts on the powerline. While that that purpose is understandable, the chemicals being used appear to have major non-target impacts, affecting herbaceous species in addition to shrubs and trees. Many of the herbicides used to control woody vegetation are, in fact, also used in ponds and lakes to suppress or eradicate Cattails. These include Rodeo, Roundup, and Arsenal, all of which are listed as used for powerline maintenance by Duke Power (see their website on Herbicide Use Within Rights of Way).

These herbicides, moreover, are both persistent and water soluble. In an active floodplain, with floodways reaching far beyond the limits of the powerline, the impacts to non-target, native vegetation may both severe and widespread. The return of freshwater marshes as a major habitat is, in fact, one of the few reversals in the trend towards losses of native species and habitats and needs to be supported rather than suppressed. This is particularly important given the likely changes in flood regimes and the advent of increasingly severe droughts and other impacts related to global climate change.

PRIMARY CONSUMERS

The cellulose, lignins, and other compounds plant produce, along with the chitin produced by lichens, are difficult for many animals to utilize. Moreover, the secondary compounds used by those species for their defense create additional obstacles that only the most specialized consumers can overcome. The transformation of plant and lichen material into a form that other organisms can use is accomplished by the primary consumers, i.e., species that are specialized as herbivores. Without this key group – which includes fungi along with animals -- other species still higher up the food web could not exist.

In virtually all terrestrial and freshwater ecosystems, insects are the most important animal group of primary consumers, with Lepidoptera being the single most important group of foliage-feeding species. Our focus on that group, along with a number of other herbivore groups – including the relatively small number of vertebrates in this category – provide an important window into the health of this particular segment of the ecosystem.

On the positive side, our survey documented 54 species of insect herbivores that are specialized on single species of plants (monophagous relationships), or on a single genus of plants (stenophagous relationships), or on just a few genera within a single plant family

(oligophagous relationships). As members of highly co-evolved complexes, these herbivores either have adaptations that prevent their over-eating their host species or have their own predators that keep their populations under control. This sort of stability allows for a stable transfer of energy and materials from the level of the primary producers to the consumer levels that is a key aspect of ecosystem integrity.

On the negative side, close associations between herbivores and their host plants makes them vulnerable to any impacts that affect their hosts. In the case of the species associated with ashes, for example, the impacts of the Emerald Ash Borer may lead to extirpation of dozens of insects and fungal species along with the ashes themselves. In our sampling of the moth fauna, we found only two micro-moths that are specialists on ash, both of which appear to be able to use the saplings that are still common in the study area.

In contrast, seven other ash-specialists that have been documented as occurring in the area were not recorded at all. Among the most tragic of these losses may be the highly co-evolved complex involving the Leafcurl Ash Aphid (*Prociphilus fraxinifolii*) and its mutualistic fungus, the Ash-tree Bolete (*Boletinellus merulioides*) (see account in the Fungi Summary). Although the bolete was recorded by Van Cotter within the New Hope Bottomlands less than five years ago, it was not found during our survey despite the extensive searches we made for it.

Similar impacts can be expected to other highly specialized herbivores if their host plants are eliminated due to competition with invading exotic species of plants. Those impacts, moreover, are not compensated by any increase in the herbivore activity due to species taking advantage of these new food sources. In most cases, native herbivores do not use these species, due to the absence of a long period of co-evolution that would allow them to both recognize these exotics as a food source and to overcome their specific anti-herbivore defenses.

As important as the impacts are of exotic species, by far the most startling finding of our survey was the massive but still mysterious decline that appears to have occurred across all macro-moths occurring within at least the bottomland portions of the study area (no macro-moth sampling was done in the upland areas of Hollow Rock Park). Compared to similar levels of sampling of this group of species done in similar habitats, some as recently as within the past ten years, the numbers of both species and particularly individuals were sharply lower in the New Hope samples, with many very common species not recorded at all.

This discovery by itself indicates that a very high level of destabilization has taken place within the New Hope ecosystem. Unfortunately, it is consistent with findings of insect declines that have been taking place at numerous sites across the planet. The cause of all these drastic declines is still enigmatic – although a lot of explanations have been proposed, no single answer has been identified as a main cause covering all examples. The declines that have occurred in the moth faunas associated with temperate deciduous woodlands – such as appears to be the

case in the New Hope Bottomlands – are particularly enigmatic. Why these taxa have suffered such great losses but other groups, such as the Orthoptera and Odonata, appear to be little affected.

SECONDARY CONSUMERS

With a huge gap opening up in the level of primary consumers, it should come as no surprise that there appear to be cascading impacts to the next levels up in the trophic hierarchy. Next to the decline of the macro-moths, the apparent reduction in the numbers of breeding birds, particularly neotropical migrants, is an important sign of the overall decline in integrity affecting the New Hope ecosystem. The possible decline in reptiles and amphibians may also reflect these impacts.

In all of these cases, however, however, there is no smoking gun that pinpoints particular causes for the observed declines; those declines themselves, moreover, need further corroboration. Potential declines in other groups of secondary consumers also need to be looked for, particularly among the bats. In groups of secondary consumers that do not appear to have suffered declines – spiders and odonates, for instance – explanations for their apparent immunity need to be determined.

DETRITIVORES/DECOMPOSERS

With the addition of Fungi, Slime Molds, and Myriapods as survey targets, we have greatly expanded our coverage of organisms that recycle dead organisms and waste products back into the ecosystem. With respect to the first two of these groups, the New Hope project area appears to be quite rich. This appears to be due to a number of positive environmental factors, such as moisture, micro-habitat diversity, and an abundance of woody debris. The age of the stand, reflecting its long-term stability – at least in the past – also contributes by allowing the accumulation of dispersers to reach the site over a long period of time. Dispersal is further aided by the presence of long-term connections to other areas of good quality habitats.

At least one of group of detritivores – the litter-feeding moths – appears to have suffered a major decline. Although probably related to the factors affecting the other groups of macro-moths, increased flooding due to development and climate change may be particularly affecting the litter layer of the floodplain and needs to be investigated as a specific causal factor.

Unfortunately, we did not obtain the same degree of coverage for some of the other important groups of detritivores. More effective sampling of beetles – one of the most important groups of wood-feeding organisms – would help provide a broader picture of ecosystem integrity within this critical trophic category. Flies, litter-dwelling mites, earthworms, and other soil invertebrates also need far more attention than we were able to devote to them.

MUTUALISTS AND COMMENSALS

Ecological interactions do not consist solely of trophic transactions, where one group benefits (the eaters) at the expense of another (the eaten); some involve forms of cooperation, where both parties receive some benefit from the interaction (mutualism) or where one benefits but does not harm the other (commensalism). Both of these types of interaction depend on long histories of co-evolution and are typically quite stable. Several such symbiotic relationships are involved in key functions without which ecosystems cannot survive.

The best-known mutualistic association in terrestrial ecosystems involves pollination, where insects and other animals feed on the pollen and nectar produced by flowering plants in return for playing a key role in the sexual reproduction of their host species by transferring pollen – sperm-containing capsules – between individuals of that species. While the pollinators do, in fact, consume products produced by the plants – including the pollen itself – the benefits to the plant far outweigh the costs represented by those losses. The production of nectar and scents as an attractant, along with the elaborate structure of flowers themselves, are additional expenditures made by plants in order to establish and maintain this function.

In the New Hope project, two key groups of pollinators were inventoried: bees and lepidopterans, including both butterflies and moths. Bees typically play the more specialized role in pollination, with a number of species being oligolectic, pollinating just a few species within a particular genus or family. In the New Hope floodplain, several such species were documented, of which *Andrena erigeniae*, a species strongly associated with Spring Beauty (*Claytonia virginiana*), appears to be the most closely associated with rich bottomlands. During its brief flight period in the spring, it was extremely abundant, a positive indicator that this key role is still functioning at a high level. Smaller numbers of *Andrena violae* were also recorded, a species that specializes on Violets, members of which were widespread in the bottomlands. The bee fauna in general was considered to be fairly representative, given the amount of survey effort that was put into them. However, many more species are expected to be found in the area with continued and more intensive inventories.

The butterfly and macro-moth fauna of the area, on the other hand, appear to be declining or at least depauperate compared to other similar areas, the macro-moth fauna catastrophically so. Although not as specialized as bees in terms of their role as pollinators, the sheer numbers of their individuals have been hypothesized to more than compensate for their more generalized services (Hahn and Bruhl, 2016; Macgregor and Scott-Brown, 2020). As pointed out by Macgregor and Scott-Brown, the decline of moth populations observed in numerous places around the globe may be having a significant effect on nocturnal pollination, which they regard as a severely undervalued function.

Some forms of zoochory – the dispersal of seeds or spores by animals – also involve mutualistic associations, where the animals obtain at least some nutritional benefit from the interaction (transport of burrs or pond organisms on the feet of ducks are more commensalistic, where the transporting organism receives no benefit). While our data are not well suited for evaluating this particular function, the abundance of Eastern Gray Squirrels that we observed in the New Hope Bottomlands probably accounts for the fairly wide distribution of Big Shellbark Hickories that we observed: squirrels are probably the only animals capable of transporting the very large nuts of that species.

Squirrels and other small mammals also play a major role in dispersing the spores of fungi, especially those involved in mycorrhizal associations with vascular plants. Mycorrhizal associations themselves are one of the most critical forms of mutualism supporting the integrity of terrestrial ecosystems: trees and other plants gain both nutrients and water from the intimate association of their roots with the mycelia of mycorrhizal fungi, with the fungi receiving sugars from the plants in exchange. While we do not have enough direct information to evaluate the health of these relationships in the New Hope project area, the general integrity of both the vascular plant community and that of the fungi indicates at least a normal degree of function in these networks. The effects of increased flooding, droughts, and loss of particular tree species such as ash all need to be investigated, however.

One important impact on the integrity of the ecosystem was, in fact, indicated by our inclusion of one highly mutualistic group in our survey: lichens. As described by Gary Perlmutter in the Summary of the Lichens of the study area, cyanolichens – those that are composed of mutualistic associations between a fungus and cyanobacteria —– are particularly susceptible to air pollution and were found in the study area almost entirely at the Hollow Rock Park, the furthest location away from the rapidly-developing zone next to the Durham-Chapel Hill Boulevard. Closer to the highway and its dense development, more pollution-tolerant species predominated.

Conservation Recommendations

In evaluating sites for conservation, there is usually an alignment between the number and degree of imperilment of at-risk species that are present in an area and the integrity of its ecosystem: a high number of imperiled species usually reflects not only a current high degree of ecosystem integrity – all of the processes involved are functioning at a high level – but also that the site has maintained that integrity over a long period of time. By conserving such sites, not only are the imperiled species given protection – a major objective in conservation – but the integrity of the ecosystem makes it a good investment of the scarce resources available for conservation.

In the case of the New Hope project area, however, these two aspects of conservation value are more at odds. On the one hand, the rare species that were among the original reasons that NHP ranked this entire area as having state significance as a natural area are still present. The population of the Big Shellbark Hickory still appears to be thriving and extends even farther to the north than previously known. Moreover, by including many more taxonomic groups in our survey, a number of other rare species have been added, which should enhance the overall value as measured by concentrations of species having a high need for conservation.

On the other hand, the ecosystem integrity of this area is clearly being impaired, and at several ecological levels. One of the major forest trees is being eliminated by an exotic pest and a number of other species are disappearing along with it, including one of the most highly co-evolved symbiotic complexes that has been recorded in the area, that involving the fungus *Boletinellus meruloides*, the aphid *Prociphilus fraxinifolii*, and the ash species themselves (see Summary for the Fungi). The new exotic wilts and ambrosia beetle infestations threaten a new range of assaults on the ecosystem, as do the dozens of other exotic species of plants and animals that have invaded the New Hope project area. The causes of the decline in the macro-moth fauna remain mysterious, but are among the worst signals of lost ecosystem integrity that we uncovered during our survey.

The changes to the New Hope ecosystem are far from unique and signal that conservation strategies and efforts need to be adjusted to take into account the new era of global decline in biodiversity that we are now entering. The most important change is that it can no longer be assumed that simply preserving high quality natural areas from the direct impacts of development will be enough to allow natural ecosystem processes, by themselves, to maintain the integrity of a natural area. Greater investments will need to be made in order to combat environmental degradation. These include more frequent monitoring of the ecosystems in order to keep track of the pace of change, as well as to gauge the effect of any conservation actions.

Taxon-specific conservation recommendations were made by each of the NCBP website groups that took part in this survey. Given that each taxon interacts with its environment – including disturbances – in very individualistic ways, we feel that the recommendations for each different group are entirely warranted. However, there are also ecosystem-wide measures that need to be considered, as discussed below.

1. **Give more consideration to the secondary impacts of development**. There are many types of environmental impacts that easily cross property boundaries: invasion of exotic species, runoff of landscaping chemicals and stormwaters, light and noise pollution, predatory incursions by uncontrolled pets all spill into adjoining natural areas. These are often termed edge impacts, with the degree of their effects related to the overall edge-

to-interior ratio – the greater the length of edges that are affected relative to the amount of natural area that is located well-away from the edges, the greater the degree of impact. Preserve designs that minimize this ratio should be preferred, with large blocks with convex outlines always preferable to narrow, constricted preserves. As was proposed in the original master plan for the New Hope corridor, protection of the steep slopes above the floodplain is desirable even where the priority is to protect the floodplains themselves. Boundaries that are positioned on the far side of the slope crests particularly help alleviate impacts that easily flow downhill. Use of wildlife-proof fences to separate developed areas from the natural habitats will help keep the wildlife out of adjoining residential areas, as well as reduce pet and human entry into the natural areas.

2. **Protect larger blocks of habitat**. Restricting conservation costs by focusing acquisitions to just the highest quality habitats – usually defined by vegetation and rare species – neglects the function of the more generalized and wide-roaming species that are also necessary for maintaining ecosystem integrity. Environmental impacts are also increasing in scale and larger preserves provide at least some greater buffer against larger, more frequent, and more severe disturbance events. The entire floodplain of New Hope Creek needs to be protected, especially given the more severe flood events that it is now appears to be experiencing. The use of fill to increase the buildable area within the floodplain should be prohibited.
3. **Maintain connectivity between habitats**. Due to increased frequency and severity of disturbance events, local extirpation of populations will become more common, with the only recovery possible based on the return of species from nearby, connected areas that have escaped the effects of a particular disaster. The more connections to potential refuges the more resilient the overall system will be. Special consideration needs to be given to potential bottlenecks, such as bridge crossings, that can limit species dispersal within an otherwise well-connected network of habitats. The needs of non-flying species need particular consideration.
4. **Allow forests to reach maturity**. The development of old-growth forests – beyond the limits recommended for harvesting timber – should be encouraged. Standing snags and wood debris in general have a beneficial effect on biodiversity and need to be controlled only where fuel build-up creates a fire hazard – a rare event in floodplain habitats. Wood-chipping as a way of increasing use of younger and otherwise commercially unimportant stands of forest should be discouraged, despite any claims that are made that it represents a benign form of energy production. Instead, the protection of natural areas for biodiversity should be coupled with the goals of carbon sequestration (see recommendations given by Daba and Dejene, 2018; Di Sacco et al., 2020; and Griscom et al., 2017)

5. **Allow the development of beaver ponds and marshes**. The restoration of beaver-created wetlands is one of the few bright spots in biodiversity conservation. From the devastation of wetland habitats created a century ago by the near extinction of beaver across much of North America (see Wohl, 2021), the recovery brought about by active re-introduction of beavers has had many beneficial impacts, ranging from biodiversity restoration to enhanced ecosystem services involving water conservation (see Jordan and Fairfax, 2021). While beavers are present in the New Hope floodplain, beaver ponds and especially marshes are poorly represented. One factor that limiting their development may be the use of herbicides to control the growth of woody vegetation under the powerline that transects much of the project area. Cattails and other marshland species appear to be the victim of non-target impacts due to the use of these chemicals, both within the limits of the powerline itself, but also in other floodways within the natural area that carry waters from the powerline well across the floodplain. In order to take advantage of beaver-habitat restoration, either more targeted methods of controlling woody vegetation – including mechanical means -- should be employed to maintain the powerline. At least, herbicides should not be employed in the vicinity of the flood channels that cross the powerline.
6. **Take aggressive action to control the spread of exotic invasives**. The spread of invasive plants and fungi should be countered by projects to remove them from the natural area. The use of highly specific, biological controls would be the best choice, but many of the most needed – e.g., those that control the Emerald Ash Borer, Chinese Privet, or Japanese Stilt Grass -- are still in the exploratory stage (see Bohannon, 2022; Shaw et al., 2018; and Nestory, 2016). Becoming involved in experimental trials should be considered and keeping up with the progress of these efforts should be a priority. In absence of effective biological control methods, mechanical removal is preferable to the use of herbicides or fungicides, both of which are likely to affect the native species of the natural area. The use of Roundup or any other glyphosate product should be avoided, as should use of any neonicotinoids, since they have persistent, broad-spectrum impacts and travel easily through the environment. Use of poisons or traps to control coyote populations should also be avoided due to the potential for non-target impacts. The need for any control of coyote populations should also be carefully evaluated, since they are at least partially restoring a predator function that has been absent in our native habitats since the destruction of wolves and mountain lions over a hundred years ago.
7. **Conduct biodiversity inventories on a much more frequent basis**. A major obstacle to achieving effective conservation of biodiversity is simply a lack of information. Conducting surveys on a frequent basis is needed just to detect the arrival of new invasives, which gives the best opportunity for eradicating them; documenting these

species long after they have spread throughout the ecosystem is a dismal prospect. A strong base of information is also needed in order to know just how certain impacts are affecting biodiversity. Currently, we know very little about the factors that are so drastically affecting the macro-moth fauna, much less how to counteract these effects.

8. **Conduct more comprehensive, multi-taxa, on-the-ground inventories**. We believe that our approach to including as many taxonomic groups as possible in our assessment of the New Hope project area has shown its worth. If we had focused on just the vegetation, or just one of the vertebrate groups, we would have missed the drastic decline of the macro-moths or the loss of many of the species associated with ash. These data, moreover, were obtained by doing ground-based surveys. While use of GIS allows many important environmental trends to be detected, covering vast areas, there is no substitute for getting key biodiversity data from actually looking for the species in their habitats. The use of an extended bioblitz approach to conducting biodiversity inventories is labor and time intensive, but we believe our findings more than justify the efforts involved. When applied to selected areas of high conservation significance and where a high degree of interest exists in maintaining and restoring biodiversity, we believe that its use can be very productive. If anything, we recommend that more taxa be included, such as bats, flies, wasps, earthworms, land snails, and litter hexapods and mites. Aquatic surveys are especially needed in any area that contains lentic or lotic habitats, including floodplain or isolated pools.
9. **Increase research on the problems facing biodiversity**. An inventory such as ours can be effective in raising questions of potential concern, but detailed answers, as well as potential remedies, need much more detailed investigation. With three research universities located within the Triangle area, there is great potential for confirming or addressing some of the issues we believe to be important for conservation of biodiversity in our area. Involvement of the NCSU Plant Disease and Insect Clinic has already played a key role in the identification of two emergent threats to the integrity of the New Hope biota. We hope that some of our other discoveries will lead to similar interests by other academic researchers. If anything, our great expansion of the species documented within the New Hope study area should help attract the interest of biologists in several disciplines. We particularly hope that the trend in academia to downgrade organismal biology and on-the-ground field research will reverse its course, given the growing realization that the biodiversity of the entire planet is becoming at risk. The question we have raised in our one-year inventory should be enough to keep researchers busy for some time.
10. **Increase the number of conservation partners**. The information gathered by this project will only be useful if it can be incorporated into the conservation planning of multiple environmental organizations. The most immediate users will be the Durham

Open Space Program, which has played an instrumental role in acquiring the preserves currently in place along New Hope Creek. The New Hope Advisory Committee should also be able to incorporate this information in order to make recommendations to the three local governments that originally established the committee to help steer conservation within the New Hope watershed. We hope in particular that greater attention will be given to the upstream areas under the jurisdiction of Chapel Hill, where there has been a recent upsurge in development within the headwaters of New Hope Creek. Chatham County, the North Carolina Wildlife Resources Commission, and the Army Corps of Engineers should also be aware of the implications of our findings for the portions of the New Hope watershed that extend downstream from our project area. All of these parties, along with the NC Botanical Garden, Duke Forest, the NC Natural Heritage Program, and representatives from local governments have been involved for several years in the Eno-New Hope Conservation Collaborative. We hope that this organization, in particular, will be able to put our findings to good use and hope they will support similar surveys elsewhere within their area of interest – thirty years of waiting for a substantial update to the biological underpinnings of conservation in this watershed has been way too long in coming!

11. **Involve the public**. In addition to attracting the attention of researchers and conservationists to the issues facing the biodiversity of the New Hope Creek study area, the support of a well-informed, highly-concerned public will be needed in order to accomplish any conservation achievements of significance. While concerns about the fate of biodiversity are growing, they are still well behind the concerns about climate change, which itself has yet to grab the attention of enough of our citizens. The mission of the NCBP is to make information about the state's native species and ecosystems as widely, freely, and easily obtainable as possible. We also encourage the public to become involved in gathering information on the state's biodiversity, with the hope that this will not only provide a wealth of new information for us to use in the websites, but also in the development of a real interest by all citizens in the fate of the world's species and ecosystems. With regard to the New Hope Creek project area itself, we plan on maintaining the website we set up for this project indefinitely, adding new information as it becomes available not only from researchers but also from members of the public. This report will also be included for anyone to read who has an interest, with the potential for adding updates as needed.

Final Word

Conservation of our native biodiversity in rapidly urbanizing landscapes presents a major set of challenges, but is representative of the difficulties facing conservation overall: simply protecting

examples of intact ecosystems in far-off places where human impacts are still low is not sufficient to achieve any lasting form of protection. There are simply too few places left that are remote enough not to suffer impacts related to human activities and even those that have had minimal impacts so far are not likely to survive intact indefinitely.

Instead, more examples are needed of successful conservation – even if not total in its benefits – in natural areas located on the actual battle lines. In this regard, successful efforts to conserve a sufficient portion of the biodiversity of New Hope Creek, allowing it to maintain at least a steady state of ecosystem integrity, may far outweigh its preservation of a particular population of rare plants or other organisms. More importantly, it is how we tackle these problems that is important. Areas that can demonstrate a successful program of conservation should receive the high degree of recognition.

References

Bohannon, G.R., 2022. Optimizing Biological Control of Emerald Ash Borer in North Carolina: Host Phenology and Parasitoid Recovery. M.S. Thesis, NCSU Dept. of Forestry and Environmental Resources. 134 pp. Available online at: https://repository.lib.ncsu.edu/bitstream/handle/1840.20/39728/etd.pdf?sequence=1

Daba, M.H. and Dejene, S.W., 2018. The role of biodiversity and ecosystem services in carbon sequestration and its implication for climate change mitigation. Environmental Sciences and Natural Resources, 11(2):1-10. Available online at: https://www.researchgate.net/profile/Mekonnen-H-Daba/publication/325349002_The_Role_of_Biodiversity_and_Ecosystem_Services_in_Carbon_Sequestration_and_its_Implication_for_Climate_Change_Mitigation/links/5b075257a6fdcc8c252baa92/The-Role-of-Biodiversity-and-Ecosystem-Services-in-Carbon-Sequestration-and-its-Implication-for-Climate-Change-Mitigation.pdf

Di Sacco, A., Hardwick, K.A., Blakesley, D., Brancalion, P.H., Breman, E., Cecilio Rebola, L., Chomba, S., Dixon, K., Elliott, S., Ruyonga, G. and Shaw, K., 2021. Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. Global Change Biology, 27(7):1328-1348. Available online at: https://onlinelibrary.wiley.com/doi/pdf/10.1111/gcb.15498

Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W.H., Shoch, D., Siikamäki, J.V., Smith, P. and Woodbury, P., 2017. Natural climate solutions. Proceedings of the National Academy of Sciences, 114(44):11645-11650. Available online at: https://www.pnas.org/doi/full/10.1073/pnas.1710465114

Hahn, M. and Brühl, C.A., 2016. The secret pollinators: an overview of moth pollination with a focus on Europe and North America. Arthropod-Plant Interactions, 10(1), pp.21-28.

Jordan, C.E. and Fairfax, E., 2022. Beaver: The North American freshwater climate action plan. Wiley Interdisciplinary Reviews: Water:1-13. Available online at: https://wires.onlinelibrary.wiley.com/doi/pdf/10.1002/wat2.1592

Macgregor, C.J. and Scott-Brown, A.S., 2020. Nocturnal pollination: an overlooked ecosystem service vulnerable to environmental change. Emerging topics in life sciences, 4(1), pp.19-32.

Nestory, S., 2016. Biological and mechanical control of Japanese stiltgrass (Microstegium vimineum). M.S. Thesis, University of Delaware, 81 pp. Available online at: https://udspace.udel.edu/server/api/core/bitstreams/c8ade834-e7f3-4441-a7fd-a5be6b6d6700/content

Shaw, R.H., Cock, M.J. and Evans, H.C., 2018. The natural enemies of privets (Ligustrum: Oleaceae): a literature review, with particular reference to biological control. CABI Reviews, (2018), pp.1-24. Available online at: https://www.cabi.org/BNI/FullTextPDF/2018/20183190112.pdf

Wohl, E., 2021. Legacy effects of loss of beavers in the continental United States. Environmental Research Letters, 16(2):1-11. Available online at: https://iopscience.iop.org/article/10.1088/1748-9326/abd34e/meta